DEVELOPMENT OF AN ATLAS OF STRENGTHS AND ESTABLISHMENT OF AN APPROPRIATE MODEL STRUCTURE

FINAL REPORT

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INTRODUCTION

Background

There are many military tasks where forces must be exerted to perform critical activities. Most of these activities are dynamic in nature and hence require the individual to exert forces in a range of postures and configurations to complete the task. The reliance on static strength capability is inadequate in such cases because of the dyanmic nature of the activity and the variance in the strength capability as a function of the position of the limb in space and/or the speeds of movements involved.

A job which can be used as an example is that of manual lifting. Based on the current literature search and laboratory work completed by Texas Tech University in this area, it is evident that dynamic strength rather than static strength data is required to assess workers' manual materials handling capacity.

During the past decade, relatively new techniques have been utilized to define acceptable load limits and methods for determining the suitability of workers for handling tasks. At the present time, Texas Tech University is defining a general model structure for manual materials handlng (MMH) activities which when completely developed can be used to establish the limits in terms of MMH activities so that individuals can perform these tasks efficiently, effectively, and without undue stress to the musculoskeletal system. Such a model will rely heavily on strength and anthropometry, hence dynamic strength would be of great value.

Dynamic strength will also be of value in job designs using static strength. Dynamic strength would be better suited than static strength because of better definition of the strength in terms of position and speed of shortening of the muscle groups involved.

Objectives

The primary objectives of this project were:

1. to develop a dynamic strength battery to assess dynamic strength capabilities of individuals and then to correlate static and dynamic strength measures; and
2. establish appropriate strength and anthropometric distributions and a demonstration of the computer accommodated model program.

Scope of Work

The first phase in this project was geared towards the development of a test battery for assessment of dynamic strength of trunk, arms, and legs for appropriate range of motion. The battery:

1. considers various levels of speed of motion,
2. is simple to administer,
3. has clearly defined, measurable responses, and
4. defines the motions to be studied.

The static strength was measured on the same subject sample in order to investigate the relationship between dynamic and static strength.

Dynamic strength data is badly needed for work-system design. Most tasks are dynamic in nature, but static strength

has been and is being used as a design parameter. This use introduces large errors especially since the correlation between static and dynamic strength is poor. Therefore, with emphasis on the design of physical tasks with demands within the population capacities, it was imperative that dynamic strength data be generated in the three-dimensional space.

The second phase of the project had two goals:

1) to develop an exclusion model; and

2) to establish appropriate strength and anthropometric distributions.

These goals were reached by the following two phases:

1. Development of an accommodated percentage model for equipment handling. The model identifies the percent of individuals from a specified male population who would be excluded from consideration for a task based on the strength requirements of the task.

2. The establishment of the underlying distribution for such strength and anthropometric variables as:

   a. shoulder strength,

   b. arm strength,

   c. back strength under a flexed posture and erect posture,

   d. leg strength, and

   e. anthropometric postural measures such as weight, stature, acromial height, arm lengths, and limb and trunk circumferences.

There exist several well known statistical "goodness-of-fit" tests which can be used to determine which of several candidate statistical distributions best describes the strength data. Some of the best known and widely used tests are the Chi-square, Kolmogorov-Smirov, and Cramer-Von Mises tests. These are discussed by Conover, 1971. Each of these tests were applied to each of the strength data sets listed above. The actual implementation was performed by means of the computer program GOF (Phillips, 1972) which is available at the Texas Tech University Computer Center. This program permits the normal distribution to be tested for quality of fit. The quality of fit of this distribution to each of the strength data sets was determined by calculating each of the three statistical test statistics listed above. The Cramer Von-Mises test statistic was used to break ties and/or make a final decision.

LITERATURE REVIEW

Dynamic Strength of Muscle Groups

The measurement of dynamic strength is a strength measurement when muscles are in action. An example would be the measurement of dynamic strength for elbow flexion from a fully extended position to a fully flexed position. The force exerted would be recorded as a function of the range and time of movement. The following sections are a review of the literature which has investigated dynamic strength in different muscle groups of the body.

Arm and Elbow

The research on dynamic movement using the arm has shown some various results. Shaver (1971) found that subjects with the greatest dynamic strength had the greatest absolute dynamic endurance (r = .93), but had a negative correlation with rel·· dynamic endurance (r = -.19). Two studies (Freund and Budigen, 1978 and Zahalak, Duffy, Stewart, Litchman, Hawley and Puslay, 1973) found similar results.

Freund and Budingen (1978) study showed the rate of rise of tension time was constant which they explained as supportive of the inability to change ballistic movements. Freund and Budingen's (1978) results were supportive of the Zahalak et al. (1973) study in which the load and velocity were found to remain independent of the EMG while the EMG remained constant with a maximal effort. Thus, the increasing EMG represnts the increasing tension.

Asmussen, Hansen and Lammert (1965) and Bender and Kaplan (1966) both found that isometric measures could indicate dynamic strength. Asmussen et al. (1965) found the force measured during concentric contractions (the muscles shorten during contraction as in lifting an object) to range from 75 to 80% of the force obtrained during isometric contractions. However, the force obtained from excentric contractions (the muscles lengthen during contraction as in lowering an object) ranged from 110 to 130% of the force of the isometric contraction. In both of these cases the speed of motion was 60% of the arm length per second or approximately 30 cm per second. For slower speeds the dyanmic forces were closer to those obtained for the isometric forces. The correlation for the slowest speed (15% of the arm length per second) and the isometric force was high ($r = .80$). Singh and Karpovich (1966) study agrees with these results adding that ecentric force is significantly less than the isometric force from 100° to 140° (0° position consisted of the subject setting upright with the forearm at a 90° angle and suppinated). Bender and Kaplan (1966) also developed a strength index found by dividing the number of pounds pulled by the body weight of the subject.

Ilai and Steinhaus (1961) looked at different psychological factors and found gunshots, shouts, hypnosis, post hypnotic suggestion and amphetamines to increase performance while alcohol and adrenaline showed no significant effects. These results show the importance of a consistent environment for subjects and how an inconsistent one can affect the individual's strength performance.

The elbow has also been used specifically in dynamic arm measurements. Several studies (Carlson, 1970; Doss and Karpovich, 1965; and Shaver, 1973) indicated good correlations (.72 - .90 in Carlson, 1970) between the isometric and dynamic strengths. Carlson (1970) also reported the absolute isometric values were higher than isotonic values. Osternig, Bates and Janes (1977) found significant correlations ($p < .05$) between isokinetic and isometric efforts but no pattern to their distribution. From these results Osternig et al. (1977) stated that they felt maximal isokinetic strength can be used to predict isometric strength. Danoff's (1978) results reflected the peak power (ft/elb/seg) was higher at loads 50% of the isometric contraction with the peak occuring earlier when the load is lighter (Figure 1). This indicates that the slope of a power curve depends on the weight of the load being lifted.

Whole Body

The measurement of dynamic strength can be applied to the whole body in addition to its application to a body segment. Clarke, Elkins, Martin and Wakim (1950) indicated that a muscle's greatest power was achieved at the highest muscular tension. Petrofsky, Rochelle, Rinehart, Burse and Lind (1975) indicated that isometric endurance is inversely related to the static component of dynamic exercise thus allowing for the prediction of the static component of dynamic strength. Nordesjo and Nordgren (1978) when comparing injured vs healthy individuals indicated that strength does decrease with an injury (Figure 2). Additionally, the differences that were found in dynamic measures

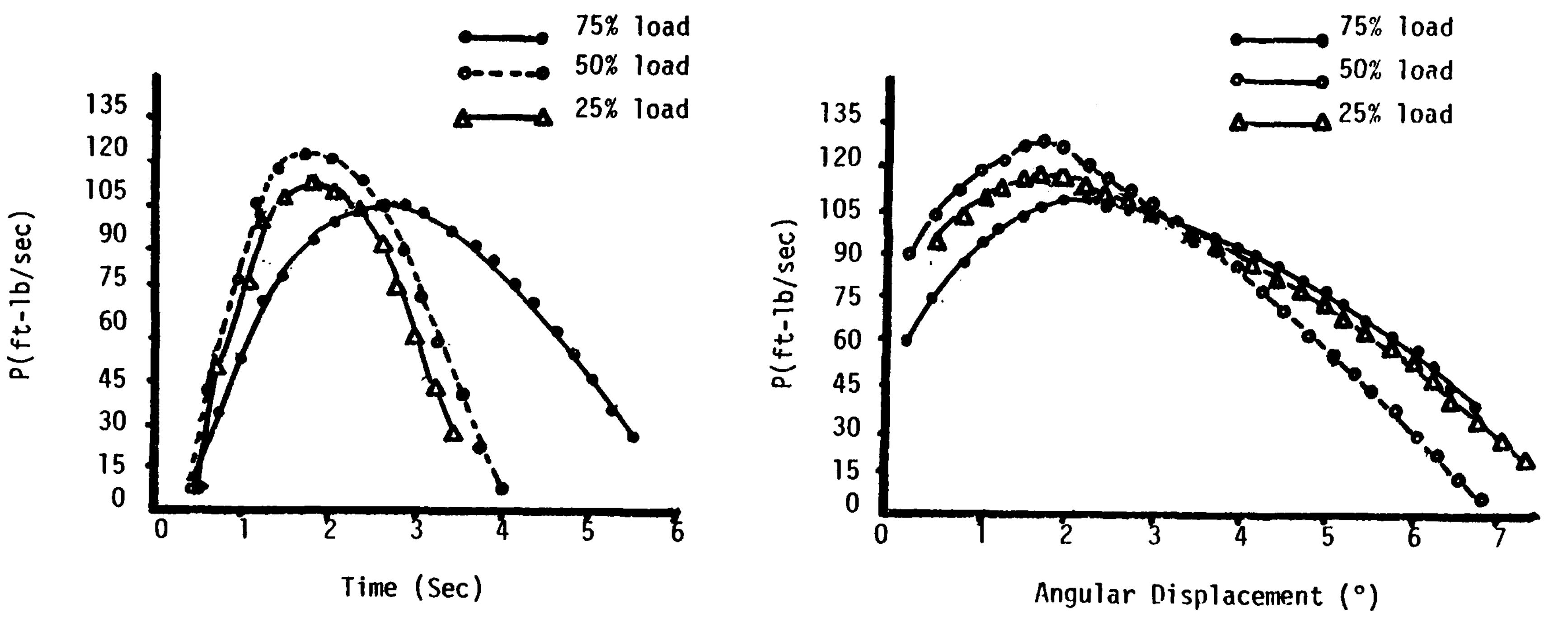

FIGURE 1. Power vs. time and power vs. angular displacement (Danoff, 1978)

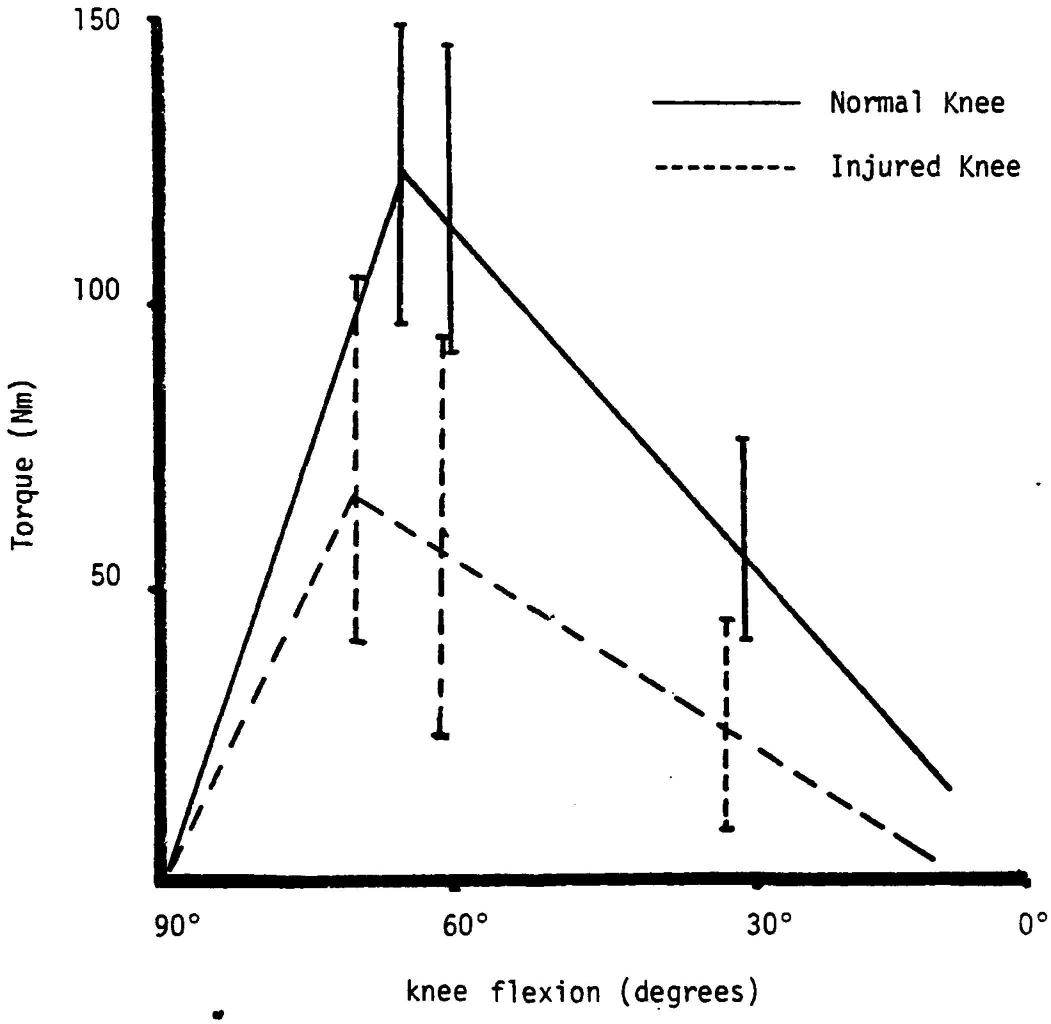

FIGURE 2. Means and standard deviations of knee extension in women having one normal and one injured knee
(Nordesjo and Nordgren, 1978)

of a healthy individual were also found in injured limbs. Laubach's (1969) study using trunk and hip show that strength measures were correlated with the lean body mass of the subject (Table 1). Also, when stature was held constant, the somatype components correlated with strength. Carlsoo (1978) and Poulsen (1978) both found high correlations between the back strength and load lifted of .7 - .8 (Poulsen, 1978). Carlsoo's (1978) study also indicated a high correlation between the back strength and abdominal muscles.

Leg

An extensive amount of research has been published in the area of dynamic leg strength. Johnson and Siegel (1978) using knee extensions reported data showing a large variability for the first three days of testing (Table 2). The data was interpreted to show that the first three trials were not stable and an experimenter should require warm-up trials in order to obtain stable data. Sargeant and Davies (1977) and Pedotti, Krishnan and Stark (1978) studied the use of both legs simultaneously in bicycling and walking, respectively. Sargeant and Davies (1977) found no difference between the leg power when used together, but the right leg showed a 3% increase when each leg was used alone in bicycling. The Pedotti et al. (1978) study showed the force patterns appeared to be the same in kinematic variables, but had different torques. Both studies must be viewed cautiously as Sargeant and Davies (1977) used only 4 subjects and Pedotti et al. (1978) used only 2 subjects.

TABLE 1. Multiple regression equations

TRUNK FLEXION STRENGTH 11.6 (Mesomorphy) + 365.6 (Body surface area) - 5.2 (Weight) - 4.8 (Skinfold: Subscapular) - 2369.2 (Body density) + 2308.0 R = .711 SE est = 18.1
TRUNK EXTENSION STRENGTH 5.2 (Skinfold: MAL X) + 4.1 (Mesomorphy) + 97.1 (Body surface area) - 2.0 (Skinfold: Triceps) - 4.3 (Skinfold: Subscapular) - 92.8 R = .741 SE est = 20.1
HIP FLEXION STRENGTH 1.4 (Skinfold: MAL X) + 1.1 (LBM-Average) = .9 (Age) - 0.6 (Skinfold: Suprailiac) - .8 (Skinfold: Suprapatella) + 10.7 R = .747 SE est = 9.2
HIP EXTENSION STRENGTH 1.1 (Stature) + 6.2 (Endomorphy) + 6.4 (Mesomorphy) = 1.0 (Skinfold: Supra-patella) - .3 (LBM-Average) = 158.5 R = .610 SE est = 11.1
TRUNK EXTENSION-FLEXION 3.5 (Skinfold: Juxta nipple) + 8.7 (Mesomorphy) - 3.8 (Skinfold: Subscapular) - 2.1 (Skinfold: Suprailiac) - .5 (LBM-Average) + 90.7 R = .627 SE est = 13.8
HIP EXTENSION-FLEXION .7 (Age) + 3.5 (Skinfold: MAL X) + 5.9 (LBM-AVERAGE) - 5.5 (Mesomorphy) - 314.9 (Body surface area) + 316.0 R = .506 SE est = 17.5

Laubach, 1969

TABLE 2. Means and standard deviations for knee extension

Days		Trials					
		1	2	3	4	5	6
1	X	37.70	38.20	37.33	38.65	39.28	39.70
	SD	14.38	12.88	12.62	13.41	13.89	14.77
2	X	38.25	39.00	39.58	39.73	39.73	40.23
	SD	12.98	12.96	13.23	12.77	13.62	14.26
3	X	38.48	39.03	39.58	40.53	40.48	40.40
	SD	13.89	14.36	14.65	15.40	14.48	14.62

Johnson, and Siegel, 1978

Thorstensson, Larsson, Tesch and Karlsson (1977) looking at active and sedentary men found skiiers and sprinters/jumpers to have the highest peak torque over other active and sedentary subjects. Torque was found to decrease as speed was increased (Ingemann-Hansen and Halkjaer-Kristensen, 1979; Perrine and Edgerton, 1978; and Thorstensson, Grimby and Karlsson, 1976). In a study by Ingemann-Hansen and Halkjaer-Kristensen (1979), the peak torque for the knee was found at a knee extension range of 90° - 20° (0° is full extension). Thorstensson et al. (1976) found that the peak torque for knee flexion occurred between 55° and 66°, while Wahrenberg, et al. (1978) reported that it occurred between 80° and 120° (0° being full extension). More research could be performed here to determine if there is a consistent peak torque between certain angles. As it appears now, there is none. Berger and Henderson (1966) and Berger and Higginbotham (1978) are both supportive of the use of static strength for predicting dynamic strength. Berger and Henderson (1966) state that static and dynamic measures are both well correlated for leg strength. The Berger and Higgenbotham (1970) study states that the angles of 61°, 89°, 135°, and 167° for knee and hip extension are the best angles for predicting dynamic from static strengths. Their correlations ranged from .79 -.99 for these angles Berger and Higgenbotham, 1970).

Static Strength of Different Muscle Groups

Static strength is the isometric exertion of force by a muscle group. Measuring static strength in the arm, for example, would entail the individual to exert as much force as possible

against an instrument which could measure the exerted force. These measurements can be taken for different muscle groups in the body such as finger strength, handgrip, arm, trunk, back, or leg strength. The measurement of static strength has been used to study predictability of strength regarding other aspects of the human such as anthropometric measurements, endurance, and different strength measures. This section is review of recent research findings regarding static strength and different muscle groups.

Fingers and Hand Grip

The research of Nordgren, Elmeskog and Nilsson (1979) on isometric abilities of the fingers reflect a difference in the appendages. Variation was found to be the largest on the ulnar rather than the radial side of the hand. This study resulted in the development of a table which gives the means and standard deviations for finger strength on 27 men and women (Table 3). This was the only study which has been found to be limited strictly to the fingers.

Research on handgrip however, has been more abundant (Caldwell, Chaffin, Dukes-Dobos, Kroemer, Laubach, Snook and Wasserman, 1974; Clarke, Hellon and Lind, 1958; Heyward and McCreary, 1977; Lind, Burse, Rochelle, Rinehart & Petrofsky, 1978; Petrofsky and Lind, 1975a, 1975b; and Stull and Kearny, 1978). The findings on grip strength have been varied. Clarke et al. (1958) found that emersion of the arm in water, at temperatures of 2, 10, 14, 18, 26, 34, or 42°C for 30 minutes

TABLE 3. Isometric maximal muscle strength in the fingers of a sample of healthy persons. X = mean, S = standard deviation in Kp.

	MEN				WOMEN			
	Right		Left		Right		Left	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	D
Opposition								
Digit. I-II	16.5	7.4	14.9	4.9	10.4	3.6	9.9	3.6
Digit. I-III	14.2	5.1	15.1	6.1	9.9	3.5	8.9	3.6
Digit. I-IV	12.1	6.4	12.9	6.0	6.7	3.6	6.8	2.5
Digit. I-V	8.9	2.6	9.8	4.0	5.5	2.0	5.2	2.5
Adduction								
Digit. I-II	7.1	2.5	6.7	2.3	5.5	1.5	4.7	1.7
Digit. I-III	2.2	1.4	2.6	1.2	2.7	1.5	2.9	2.5
Digit. I-IV	1.4	0.6	1.6	1.0	1.3	0.6	1.9	1.7
Digit. I-V	1.2	0.8	1.3	1.0	1.2	0.5	1.3	0.8
Abduction								
Digit. I-II	1.11	0.55	1.05	0.61	0.92	0.43	0.81	0.50
Digit. I-III	1.02	0.61	0.97	0.57	0.90	0.37	0.79	0.37
Digit. I-IV	0.63	0.42	0.65	0.45	0.65	0.40	0.67	0.40
Digit. I-V	0.63	0.48	0.60	0.20	0.64	0.33	0.64	0.34

Nordgren et al. 1979

affected the endurance of a subject. Eighteen degrees centigrade was found to be optimum temperature, and any temperature above or below this was found to reduce endurance. Heyward and McCreary (1977) found no correlation (r = .00) between maximum strength and endurance.

The research of Caldwell et al. (1974) dealt with the effect instructions have on grip strength performance. Each subject was told to jerk, increase, or hold the grip. The results indicated that the jerk worked best and is fastest for obtaining the maximum strength measure (Figure 3). Caldwell et al. (1974) emphasized that these results show the importance of instructions on the subjects' performance. Therefore, the conclusion was that the instructions given to the subject should be reported in the research.

Another aspect of methodology was studied by Stull and Kearny (1978) regarding recovery time. They found, for an endurance test at 50% maximum voluntary contraction, the percentage recovery was 20% in 5 seconds, 50% after 42 minutes, 40 seconds, and complete recovery at the end of 4 hours time. This information would be a very important consideration to be made if someone is considering a design making use of repeating measurements.

Lind et al. (1978) looked at the effect of posture on strength performance. They measured the subjects on a hand dynamometer while: 1) seated, or on a tilt table; 2) with the table at a 45° angle, the head up; 3) lying down; or 4) with the table at a 15° angle, head down. Lind et al. (1978) found that posture had no effect on the subjects' grip strength.

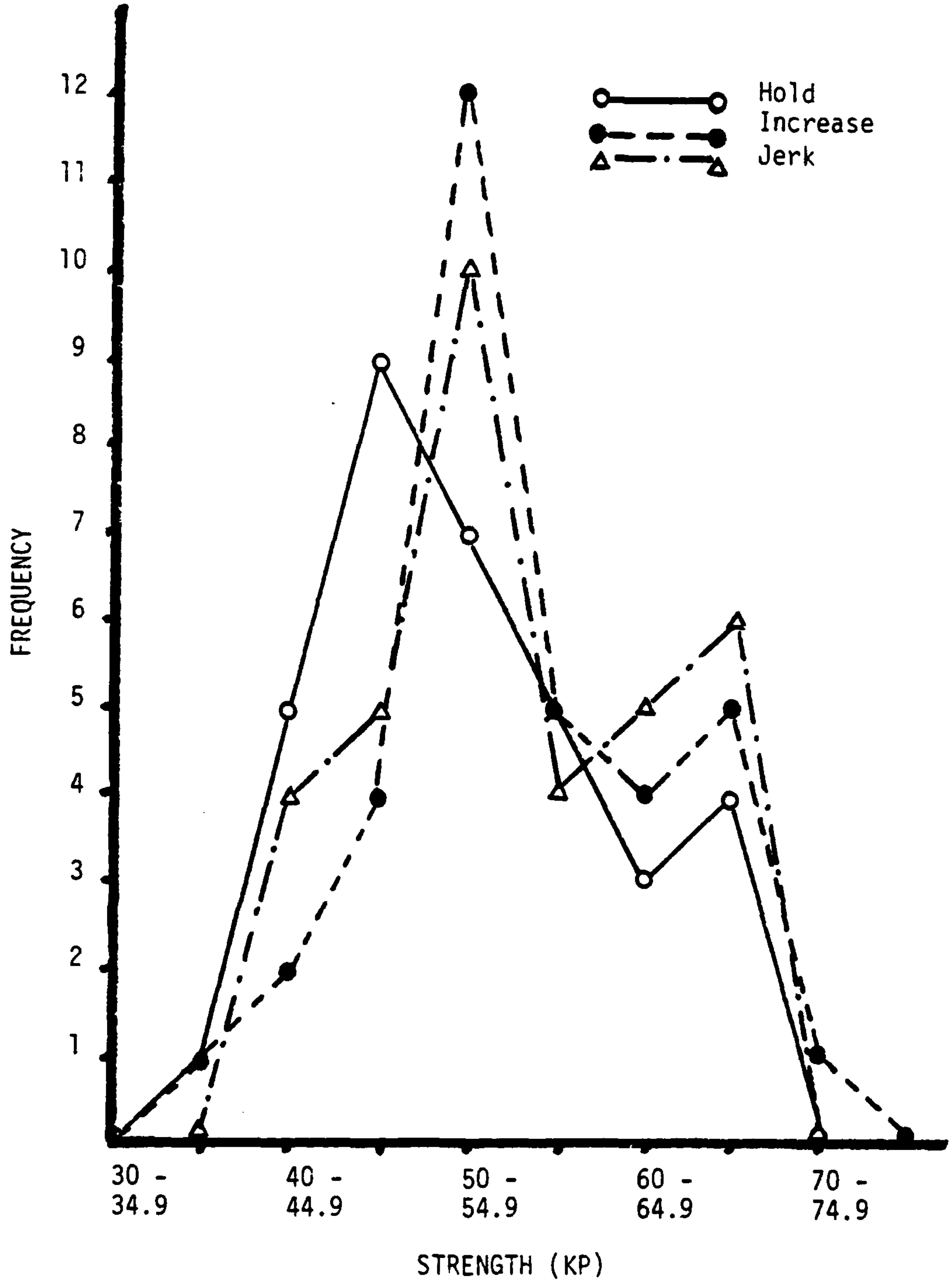

FIGURE 3. Distribution of maximum grip strengths for three instruction categories (Caldwell, et al., 1974)

Kroll (1971) measured wrist flexion in women and found no physiological factors affecting fatigue. He used three groups of subjects divided in to high, medium and low strength. The high strength group was found to suffer from the greatest loss of strength after a maximum of exertion. They recovered about 86% of their maximum strength while the low strength group recovered completely (107 - 108%). The author does point out that the values given may be somewhat misleading since the first measures are usually not the strongest therefore accounting for the 107 - 108% recovery.

Arm

Handgrip strength and arm strength in combination were used by Laubach, Kroemer, and Thordsen (1972). They found body weight to be a good predictor ($r = .34$ to $.49$) for the arm force. The correlation between force exerted on hand operated controls and grip strength was reported at $r = .21$ to $.36$. Laubach's et al. (1972) reaction to these results were that it could explain 4% to 13% of the variation in the use of controls. Lamphiear and Montoye (1976) studied arm and grip strength also. Their results showed that strength could be prediced from anthropometric measures. Svoboda (1973) took measurements on the forearm which indicated the correlation between strength and endurance was low. Carlson and McCraw (1971), however, found a negative correlation ranging from -.46 to -.60. These two studies leave some disagreement as to whether endurance can be predicted from strength.

Back

Poulsen (1970 and 1978) in measuring back strength found that neither a fixed standard load nor the weight of the subject could be used as predictors. A good predictor appears to be the relationship between back strength and the maximum load lifted. Poulsen (1970) derived a formula for males and females for predicting maximum load recommending that men and women only lift up to 70% of this maximum.

Maximum load (kg) = back muscle strength (kg) (Males)

Maximum load (kg) = back muscle strength (kg) - 8 kg (Females)

Leg and Knee

The next group, the leg muscles, has received a large amount of research in relation to the other muscle groups. Ayoub, Bethea, Bobo, Burford, Caddel, Morrissey and Intaranont (1980) have compared isometric leg strength of low coal miners to reference populations. Their results indicate the miners have significantly stronger leg strength than do the comparison populations. It is felt this is due to the job demands placed on the miners which has created the occupational differences.

Tesch and Karlsson (1977) and Viitasalo and Komi (1978) found the muscle fiber to be influential on the form of the force-time curve. Viitasalo and Komi (1978) also reported that the force-time measurement can be used to indicate the rate of force production because of its fair reliability. Tesch and Karlsson (1977) found that lactate concentration correlated well with the number of fast twitch fibers ($r = .89$). This indicates that the type of muscle (whether there are more fast twitch or

more slow twitch fibers) can affect the isometric strength in that muscle.

Start, Gray, Glencross and Walsh (1966) found speed and power appeared to be similar in leg strength but had little association with one another. Currier (1975) found the greatest force in the quadriceps to occur when the knee was extended, starting from the position of a 60° angle. He also used a wedge under the quadriceps to see if there was any effect on the subjects performance. He found no difference with or without the wedge.

Kroll and Clarkson (1978), Murray, Baldwin, Gardner, Sepic and Downs (1977) and Haffajee, Moritz and Suantisson (1972) looked at the knee extension. Haffajee et al. (1972) found the maximum dynamic strength occurred at a 40° angle of knee flexion. Corlett and Bishop (1975) found no significant strength differences between the right and left leg while using a horizontal foot pedal. Cooper, Grimby, Jones, and Edwards (1979), looking at the psychological perception of muscle strength in the quadriceps, found the perceived maximum strength was in actuality only a percent of the actual maximum strength (Figure 4).

Edwards and Hydes' (1977) results on quadriceps and hand grip found the strength of the quadriceps to be equal to 75% of the body weight. The result of body weight in any way being related to strength is interesting given there was no relation with body weight and arm strength. This could be an indication of how the different uses of arm and leg strength are affected.

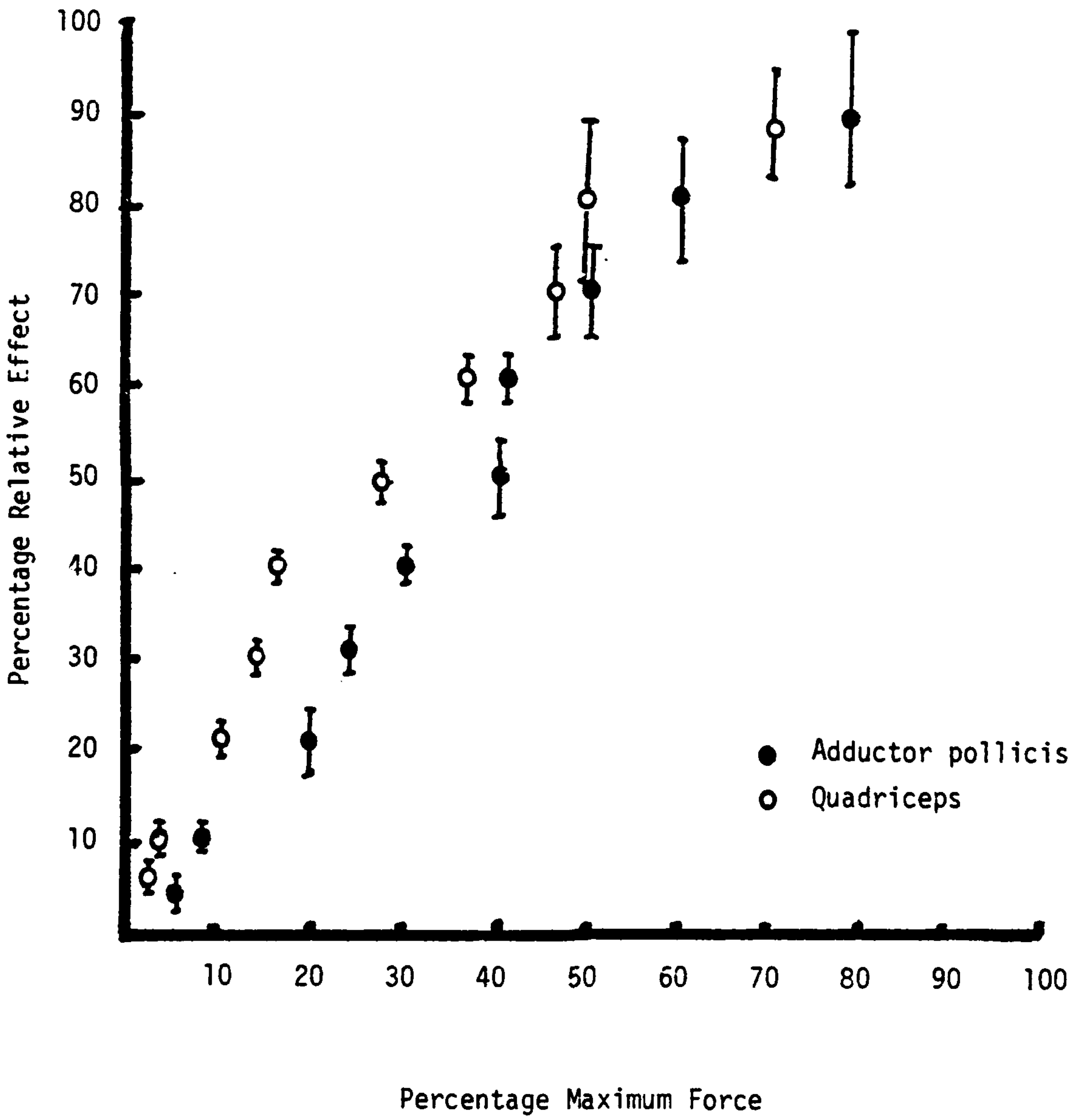

FIGURE 4. Mean values with standard deviations for the estimation of subjects' perceived effort (Cooper et al., 1979)

Whole Body

The next studies look at strength measurements involving large portions of the body. Christensen (1975) using the back and leg extension, found no difference between the two when expressed in strength per pound of body weight or lean body weight. Several studies have looked at overall body strength (Asmussen and Heebol-Nielson, 1961; Knapick, Kowal, Ritey, Wright and Sacco, 1970; and laubach and McConville, 1969). Laubach and McConville (1969) developed correlations between body size and muscle strength. neither the body size, typology, or compostion were found to be effective predictors of strength (Table 4). Knapik et al. (1979) developed an apparatus for the testing of muscle strength. When using the apparatus, measurements on the upper body and legs were found to have been more reliable than the measurements on the trunk.

Ayoub, Bethea, Deivanayagam, Asfour, Bakken, Liles, Mital and Sherif (1978) also measured back strength. They developed a simple model to obtain the maximum acceptable weight of lift by subtracting body weight from a calculated value. The calculated value was derived using sex, weight, arm strength, age, shoulder height, back strength, abdominal depth and dynamic endurance. Lifting norms were developed for males and females (see Table 5). The capacity values are a function of the height of lift at a frequency of one lift per minute.

TABLE 4. Simple and partial correlation coefficients between measures of muscle strength and body size and typology†

	Hip-Flexion Strength	Hip-Extension Strength	Trunk-Flexion Strength	Trunk-Extension Strength	Elbow-Flexion Strength	Shoulder-Flexion Strength	Knee-Flexion Strength	Knee-Extension Strength	Shoulder-Inward Rotation Strength	Ankle-Plantar-Flexion Strength	Ankle-Dorsi-Flexion Strength	Hand-Grip Strength	Mean Total Strength
Weight	30*	18	39*	53*	50*	40*	33*	19	43*	28*	29*	41*	49*
	—	—	—	—	—	—	—	—	—	—	—	—	—
	25*	10	38*	51*	43*	37*	30*	22	44*	24*	20	31*	45*
	—	—	—	—	—	—	—	—	—	—	—	—	—
Stature	17	20	13	20	29*	17	13	00	11	15	26*	31*	22
	04	13	-07	-08	07	-04	-04	-11	-12	02	14	14	-02
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—
Skinfold: Triceps	06	-15	07	23*	00	-01	04	-04	21	04	07	-03	06
	-07	-25*	-10	03	-25*	-20	-10	-13	04	-08	-21	-23*	-17
	08	-14	08	25*	03	01	06	-04	22	05	-05	-01	08
	-06	-22	-13	00	-24*	-23*	-12	-18	00	-08	-17	-20	-19
Skinfold: Subscapular	-06	-16	05	24*	00	00	09	-08	-02	-04	-15	-06	01
	-25*	-29*	-18	-03	-33*	-25*	-09	-21	-31*	-22	-36*	-33*	-31*
	-04	-14	07	27*	04	02	11	-08	-01	-02	-13	-03	04
	-26*	-26*	-24*	-08	-34*	-31*	-12	-30*	-41*	-24*	-33*	-30*	-36*
Skinfold: Suprailiac	-09	-17	11	22	10	-05	03	-09	16	-03	-07	-09	02
	-25*	-28*	-07	-02	-16	-27*	-13	-19	-03	-17	-23*	-32*	-24*
	-06	-14	14	26*	15	-02	05	-09	18	00	-03	-04	06
	-27*	-25*	-12	-07	-14	-33*	-16	-28*	-10	-19	-19	-29*	-29*
Lean Body Mass	37*	31*	42*	50*	58*	49*	35*	27*	46*	35*	40*	49*	56*
	24*	35*	16	05	35*	31*	15	23*	18	24*	34*	30*	33*
	34*	24*	44*	50*	56*	50*	36*	35*	51*	34*	32*	40*	37*
	27*	34*	25*	11	38*	41*	21	36*	31*	28*	32*	28*	42*
Head and Neck Length	00	15	-02	-13	04	02	-01	-05	-01	09	01	10	00
	-02	14	-05	-20	01	-01	-03	-06	-04	08	-01	09	-04
	-11	06	-10	-28*	-14	-08	-09	-06	-08	02	-15	-07	-14
	-05	08	-01	-19	-04	02	-02	00	03	08	-11	01	-03
Torso Length	22	32*	23*	33*	26*	25*	15	10	13	23*	18	31*	31*
	06	26*	01	03	-05	02	-05	-02	-17	08	02	10	04
	14	25*	21	28*	07	19	08	15	07	17	00	13	23*
	05	23*	07	10	-11	05	-04	07	-12	09	-09	01	07
Upper Trunk Length	21	25*	29*	38*	18	12	19	12	08	15	06	26*	29*
	06	19	10	13	-12	-12	02	02	-20	00	-12	05	04
	14	17	26*	33*	02	03	14	15	02	08	-11	10	21
	05	14	15	18	-17	-12	04	08	-16	-01	-20	-01	06
Lower Trunk Length	08	19	-02	02	20	27*	-02	-01	11	19	25*	17	13
	01	16	-12	-13	09	19	-10	-06	00	13	19	08	01
	01	12	-08	-08	08	22	-08	-01	07	13	15	04	03
	00	12	-10	-11	07	23*	-10	-02	06	13	15	03	02
Arm Length	12	03	13	12	36*	14	08	-02	16	-01	23*	34*	15
	00	-05	-04	-13	19	-04	-07	-12	-02	-14	13	20	-06
	-03	-22	04	-07	21	01	-04	-03	12	-22	04	16	-04
	-04	-22	02	-11	21	-02	-06	-05	11	-24*	03	15	-07
Thigh Length	-09	-08	-04	02	23*	-03	-06	-10	05	05	29*	10	00
	-18	-13	-17	-14	12	-14	-15	-16	-07	-03	23*	00	-14
	-25*	-26*	-16	-13	06	16	-17	-13	-02	-06	27	-11	-17
	-24*	-26*	-15	-12	10	-15	-16	-12	00	-05	18	-10	-16
Calf Length	15	09	11	17	29*	18	14	02	12	15	34*	29*	21
	03	02	-07	-06	11	02	01	-07	-07	04	25*	15	01
	00	-15	-01	01	09	08	06	04	04	04	24*	06	04
	00	-15	-01	01	10	09	06	04	04	04	24*	06	04
Endomorphy	10	07	25*	43*	22	26*	21	12	31*	27*	21	12	31*
	-12	-06	01	14	-14	01	01	00	06	12	03	-20	00
	12	09	27*	46*	27*	28*	23*	12	33*	29*	25*	16	35*
	-13	03	-05	12	-13	-02	-02	-09	-03	16	15	-15	-01
Mesomorphy	30*	25*	40*	32*	37*	49*	22	32*	47*	20	18	44*	43*
	20	20	28*	12*	20	38*	09	2e*	34*	09	06	32*	30*
	32*	29*	42*	35*	42*	52*	23*	32*	49*	22	22	50*	49*
	23*	28*	27*	10	25*	41*	08	24*	33*	11	13	42*	32*
Ectomorphy	-09	-01	-14	-09	-01	-20	-08	-17	-24*	-10	03	01	-14
	-04	00	-14	-09	01	-21	-08	-17	-26*	-10	04	02	-14
	-35*	-26*	-38*	-39*	-39*	-32*	-28*	-27*	-53*	-35*	-27*	-38*	-50*
	-26*	-27*	-17	-05	-13	-39*	-10	-16	-34*	-26*	-19	-24*	-28*

† The first row of coefficients are zero-order correlations; the second and third row are first-order partial correlations with weight and stature held constant respectively; and the fourth row of coefficients are second-order partials with both weight and stature held constant. Decimal points are omitted.
* Significantly different from zero at the 0.05 level of confidence

TABLE 5. Distribution of maximum weights (lbs.) of lift acceptable to male and female industrial workers* (corrected for one lift/min.)

Height of Lift	Sex	Mean	Std. Devia.	PERCENT OF POPULATION										
				95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	Male	61.17	16.86	33.43	43.67	49.62	54.66	59.06	61.17	63.47	67.67	72.71	78.66	88.90
	Female	37.12	6.76	26.00	30.12	32.50	34.52	36.27	37.12	37.96	39.72	41.73	44.11	48.20
Floor to Shoulder	Male	51.21	12.11	31.29	38.64	42.91	46.53	49.69	51.21	52.72	55.88	59.50	63.77	71.13
	Female	31.08	6.54	20.32	24.29	26.60	28.55	30.26	31.08	31.78	33.60	35.56	37.86	41.83
Floor to Reach	Male	49.12	11.20	30.69	37.50	41.45	44.79	47.72	49.12	50.52	53.44	56.79	60.74	67.54
	Female	28.14	5.41	19.24	22.52	24.43	26.05	27.46	28.14	28.81	30.23	31.84	33.75	37.04
Knuckle to Shoulder	Male	57.75	14.67	33.33	42.25	47.42	51.80	55.63	57.47	59.30	63.13	67.52	72.69	81.60
	Female	31.97	6.55	21.19	35.17	27.48	29.44	31.15	31.97	32.78	34.50	36.45	38.76	42.74
Knuckle to Reach	Male	53.54	10.70	35.93	42.44	46.21	49.40	52.20	53.54	54.87	57.67	60.87	64.64	71.14
	Female	26.22	4.86	18.22	21.17	22.89	24.35	25.61	26.22	26.83	28.09	29.55	31.26	34.21
Shoulder to Reach	Male	43.62	10.45	26.43	32.77	36.46	39.58	42.31	42.62	44.92	47.65	50.77	54.46	60.81
	Female	25.78	4.17	18.92	21.45	22.92	24.17	25.26	25.78	26.30	27.39	28.63	30.10	32.64

*Assuming a normal distribution

Relationships Between Muscle Strength and Endurance

Fitting the task to the worker can be best achieved by knowing both the demands of the task and the worker's capacities. The physical demands of the task can be determined by applying a task analysis procedure, while the worker's muscular capacity can be determined by measuring his maximal muscle strength and endurance.

Muscle endurance is defined by the type of muscle contractions. If the muscle is doing static contractions, the endurance will be defined as static or isometric muscle endurance. On the other hand, if the muscle is doing dynamic contractions, the endurance will be defined as dynamic or isotonic muscle endurance. Another form of dynamic endurance is isokinetic endurance which has been less commonly investigated.

Dynamic Muscle Endurance

Shaver (1971) measured the absolute isotonic endurance by the number of times a subject could lift a common load equivalent to 75% of the group's mean maximum isotonic strength. Maximum strength was defined as the load with which one complete movement could be performed using maximum muscular exertion. He also measured the relative isotonic endurance by the number of times an individually determined load representing 75% of the subject's maximum isotonic strength could be lifted. Shaver (1971) found a high correlation ($r = 0.93$) between those individuals with the greatest isotonic strength and those having the greatest absolute isotonic endurance ($p < 0.01$). However, the correlation between maximum isotonic strength and relative isotonic endurance obtained from this study was -.19 ($p > 0.01$).

Shaver (1973) observed that persons with high maximal isometric strength also have high relative isotonic endurance when using 35, 40, and 45% of their maximum isometric strength. He suggested that isotonic endurance tests at given percentage levels of maximum strength can discriminate between levels of strength of atheletes.

Isokinetic endurance has not received the attention devoted to isotonic endurance. Only one study was found in the literature Patton, Hinson, Arnold, and Lessard (1978) which gave a definition for isokinetic muscular fatigue, adopted from some material circulated by Lumex, Inc., manufacturers of Cybex and Orthotron instrumentation. Patton et al. suggest that muscular fatigue occurs when the torque recorded from a given contraction is one-half that of the initial torque produced.

Isometric Muscle Endurance

In reviewing the literature, it was found that several indices have been established for measuring isometric muscle endurance. Tuttle, Janney, and Thompson (1950) defined the absolute endurance index as the average isometric muscle strength maintained for a specified time (usually 60 seconds) expressed in force units (kilograms or pounds). They also defined the percentage of maximum strength maintained for that period (strength endurance) as the percentage obtained by dividing the absolute endurance index by the maximum muscle strength. Consequently, many researchers (Tuttle, et al., 1955; Caldwell, 1964a; McGlynn, 1969; and McGlynn and Murphy, 1971) used these definitions in their studies. A third index which is relative isometric

endurance, which is defined as the number of seconds the muscle group can maintain a tension that is a specific proportion of its maximal isometric strength. This index has been used by several investigators (Caldwell, 1963; and 1964b; Start and Graham, 1964; Carlson and McCraw, 1971; Nobel and McCraw, 1973; Heyward, 1975; and Heyward and McCreary, 1977 and 1978). By comparing the absolute endurance index and the relative isometric endurance, Caldwell (1964a) concluded that there is no way of saying which index is better than the other.

Some investigators were interested in studying the isometric fatigue curves (i.e., the curves showing the force exerted as a function of time) either for males (Royce, 1958; and Kroll, 1968) or for females (Kroll, 1971; and Kearney, et al., 1976). Fatigue patterns were observed to be different for different levels of strength. Therefore it was deduced that it is unlikely the same factors responsible for muscular fatigue can be operating in the same manner at different levels of isometric strength (Royce, 1958; and Kroll 1971). The fatigue curves under normal and occluded circulatory conditions (Kearney, et al., 1976), were found to be very similar up to a period of about 50 to 60 seconds after which the curves were significantly different.

In discussing the factors affecting isometric muscle endurance, many researchers (Start and Graham, 1964; McGlynn, 1969; McGlynn and Murphy, 1971; and Carlson and McCraw, 1971) claimed that during a maximum isometric contraction the intramuscular pressure rises above the arterial pressure in the muscle. The exerted force results in the occlusion of blood to

the muscle. As a result, a major part of the energy for sustained contraction depends upon the amount of aerobic energy reserves in the muscle. Accordingly, the factors determining endurance are the energy available and the demand made upon that energy. Also, it is assumed that the build-up of biochemical fatigue products in isometric contraction is related to the amount of force exerted by the muscle. Individuals exerting high levels of maximum strength, therefore, would produce more biochemical fatigue products than those of a weaker group. For stronger subjects, one could expect an earlier onset of fatigue as a result of the larger amount of fatigue products present in the muscle (McGlynn, 1969; and McGlynn and Murphy, 1971).

The point at which the degree of intramuscular tension overcomes the force of blood pressure and totally occludes intramuscular circulation is defined as the Critical Occluding Tension Level (COTL). To determine COTL, many studies have been conducted using two groups of subjects, one with the circulation intact and the second with artificially occluded circulation (Royce, 1958; McGlynn and Murphy, 1971; Heyward, 1975, Kearney, et al., 1976; and Heyward and McCreary, 1978). Royce (1958) showed that COTL occurred when the exerted force was 60% of the maximum voluntary contraction (MVC). Heyward (1975) reported that COTL occurred at 60% MVC for low strength males and at 45% MVC for high strength males. For female subjects, Kearney, et al., (1976) concluded that COTL occurred at 52% MVC, while Heyward and McCreary (1978) reported that COTL occurred at 60%

MVC which is the same as that reported for low strength men by Heyward (1975).

Contradictory results have been reported concerning the relationship between strength level and relative endurance. Several researchers (Tuttle, et al., 1950; Tuttle, et al., 1955; McGlynn, 1969; McGlynn and Murphy, 1971; Carlson and McGraw, 1971; Nobel and McCraw, 1973; and Heyward, 1975) emphasized the ability of weaker subjects to maintain a higher proportion of their maximum strength than stronger subjects; in other words, a significant negative correlation between strength and relative endurance exists. However, other investigators (Caldwell, 1963; 1964a; and 1964b; and Start and Graham, 1964) found no significant correlation between strength and relative endurance. Heyward and McCreary (1977) reported no relationship between maximal strength and relative endurance (r = .00) for women athletes. They claimed that if the relationship between strength and relative endurance is a function of changes related to hypertrophy of muscle tissue. it might be hypothesized that the negative relationship betwen these two factors would not be present for women.

Kroll (1968) observed that a low level of strength group always demonstrated a fatigue pattern significantly different from high and middle level groups. In another study, Kroll (1971) concluded that an overall or composite fatigue curve which has an average set of values for any sizable group of subjects will seldom represent the actual fatigue patterns expressed by all the subjects in the sample.

Finally, the literature review revealed a lack of information concerning muscle endurance for females. Most of the endurance studies found in the literature utilized males as subjects. Muscle endurance data for females has become of great importance as the number of females entering the work force is increasing.

Effect of Training on Muscle Strength

Salter (1955) observed that training of supination of the left hand of either isometric or isotonic contractions for a period of four weeks, four days a week improves muscle strength significantly ($p < .01$) for both male and female subjects. The average increase in muscle strength due to these training procedures was found to be approximately 64%. No correlation was found between degree of muscle strength improvement and fatigue experienced in training. Also, the difference in the muscle strength improvements due to training of isometric or isotonic contractions was not significant.

Pipes and Wilmore (1975) studied the effect of three different training procedures, i.e., isotonic contractions, isokinetic low speed contractions, and isokinetic high speed contractions. Their results revealed that isokinetic resistance training procedures are significantly better in affecting changes in muscular strength, body composition, and motor performance tests than standard isotonic resistance training procedures. The average percentage increases in isometric strength, isotonic strength, and isokinetic strength due to the three different training procedures are given in Table 6.

TABLE 6. Average static, isotonic, and isokinetic strength increase due to three different training programs

Type of Training / Type of Strength	Percent Increase in Muscle Strength		
	Isotonic Training	Isokinetic Low Speed Training	Isokinetic High Speed Training
Isometric Strength	6.7	27.5	23.1
Isotonic Strength	14.9	13.8	19.2
Isokinetic Strength	1.3	21.2	39.6

After, Pipes and Wilmore, 1975

The effects of an eight week period of systematic progressive strength training on the EMG activity of the leg extensor muscles were investigated by Thorstensson, Karlsson, Viitasalo, Luhtanen, Komi (1976). The EMG analyses showed no significant alterations in the investigated leg extensor muscle due to the applied strength training program.

Pipes (1978) compared the changes in muscle strength, body composition and anthropometric measures for groups training with constant resistance (CR) and variable resistance (VR) training procedures. Strength training was conducted 3 days per week, 45 min per day, for 10 weeks. Pipes reported the percentage strength improvements assessed by constant resistance testing procedures to be 25.4 and 8.9 for CR and VR training respectively. The percentage strength improvement were 9.5 and 25.5 for CR and VR training when the strength was assessed by variable resistance testing procedures. He emphasized that the training groups did have changes in body composition, lean body weight, absolute and relative body fat, and increases in the limb circumferences.

Asfour (1980) and Asfour and Ayoub (1980) give a description of a six week training program that successfully increased the maximal oxygen uptake, isometric strength, and the lifting capability of ten male student subjects. The subjects trained for 5 days per week. The program included training for flexibility, muscle strength (by applying the concept of progressive resistance exercise), muscle endurance (by lifting light loads at a high frequency of lift), and cardiovascular endurance (by exercising on a bicycle ergometer).

The results of the training program showed an increase in the maximal oxygen uptake of the subjects. An increase in back, arm, leg, and shoulder isometric strength also occurred. The maximal amount of weight lifted in a compact box, for different heights of lift, increased significantly by training. Table 7 gives the mean values of the different isometric strength measures before and after training. Based on the data in Table 7, the authors concluded that most of the increase in isometric strength took place during the first two weeks of the training program (the first 10 sessions).

Effect of Body Composition On Muscle Strength

Thorstensson, Grimby, Karlsson (1976) performed standardized measurements of dynamic strength of the knee extensor muscles by means of isokinetic contractions to study force-velocity relationships. Peak torque was found to decrease with increased angular velocity and to occur at an approximate knee angle of 60 degrees, (0 degrees = fully extended knee). Significant correlations between peak torque values and the relative area of Fast Twitch (FT) fibers were found for only the highest contractile speed (180 degrees/sec). The individual maximal speeds of contraction were also found to be related not only to the relative area of FT fibers but also to the percentage of FT fibers. These correlations indicate a role for muscle quality in terms of fiber types in determining dynamic strength in certain situations.

Thorstensson, Larsson, Tesch, Karlsson (1977) studied the strength performance in athletes of different disciplines and sedentary men under standardized isokinetic conditions. Slow

Table 7. Mean Value of the Different Static Strength (lbs) Measures Before and After Training (Based on 10 Subjects)

Static Strength	Strength Before Training (lbs)	Strength After 10 Training Sessions (lbs)	Percent Increase	Strength After 20 Training Sessions (lbs)	Percent Increase	Strength After 30 Training Sessions (lbs)	Percent Increase
Shoulder	124.8	135.7	9.74	138.4	10.90	141.9	13.7
Arm	91.0	113.3	24.54	121.6	33.63	123.6	35.8
Composite	306.1	350.9	14.63	359.8	17.54	365.1	19.3
Back Strength I	247.2	305.6	23.62	317.2	28.32	320.2	29.5
Back Strength II	165.9	204.5	22.55	211.8	26.90	216.3	29.6
Leg	336.1	378.1	12.50	391.5	16.48	400.6	19.2
Overall	1269.3	1488.2	17.24	1540.0	21.33	1567.7	23.51

Asfour, 1980

twitch fibers were found to predominate in endurance athletes. Thorstensson, et al. (1977) also emphasized that fast twitch fibers are important for force output during fast contractions and training does help the development of fast twitch/slow twitch area ratios, consequently training improves force production.

Tesch and Karlsson (1977) reported that after a short period of isometric exercise, lactate concentration as expressed by lactate ratio (lactate concentration in fast twitch (FT) fibers/lactate concentration in slow twitch (ST) fibers) was found to be positively correlated to the percent of FT fibers ($r = 0.89$). At the onset of isometric exercise, the increase in lactate concentration was faster in ST fibers when the muscle rich in ST fibers and faster in FT fibers when the muscle was rich in FT fibers. They concluded that exhaustion is primarily related to whether fast or slow twitch fibers are innervated by the recruited motor nerve.

Viitasalo and Komi (1978) concluded that force-time measurement in isometric bilateral leg extension movement is fairly reliable, and can be used to indicate the rate of force production. They observed that the time to reach various force levels is related to the percentage of slow twitch fibers. Athletic subjects were found to have force-time curves different from the normal subjects. They emphasized that strength training programs can influence the form of the force-time curve even for subjects with similar muscle fiber composition.

Larsson, Grimby, and Karlsson (1979) found that isometric and isokinetic strength increased with age up to 20-29 year

group, then leveled to the 40-49 year group and finally decreased with the older groups. The biopsy data of their study revealed a shift toward low percentage fast twitch muscle fibers while slow twitch muscles increased with an increase in age. Fast twitch muscle fibers showed a significant ($p < .01 - .001$) correlation with isometric and isokinetic strength. Thus they suggested that the primary causes of the decline in strength during aging are the age-dependent decrease in the total number of muscle fibers together with the muscle fiber atrophy.

Ingemann-Hansen and Halkjaer-Kristensen (1979) obtained an estimate of the peak torque-velocity relationship in an experimental subject from the slope of the regression line. No correlation was demonstrated between the slope and the fiber composition in the lateral portion of the quadriceps muscle.

Finally, the literature review revealed a lack of information concerning muscle endurance for females. Most of the endurance studies found in the literature utilized males as subjects. Muscle endurance data for females has become of great importance as the number of females entering the work force is increasing.

Effects of Age and Sex on Muscle Strength

Two variables which experimenters often consider are the age and sex of the subject. Both of these variables affect human capacities. The following is a review of the literature of each area; age, sex and a combination of both.

Age

Age is a factor that has a significant effect on human capacities. An important quesition then becomes, how does age change one's performance? The only longitudinal study dealing with age is recorded by Nylind, Schele and Linroth (1978). Fifty five males were measured at the age of 19 on physical working capacity, muscular strength, blood pressure and body dimensions. At the age of 30, the subjects showed both a weight increase and a strength increase while the heart rate remained the same as it was at the age of 19 (Table 8). The strength measurements were taken on handgrip and shoulder pull. The subjects used would not be considered old thus the increase in strength is really not suprising.

Petrofsky and Lind (1975) recorded static handgrip for 100 males. The means were calculated for 4 age groups: 20-29, 30-39, 40-49, and 50 years and above. They found the 50 year old and above group to have an increase in blood pressure while the 20-29 year olds had the greatest increase in heart rate. An unexpected finding was the lack of decrease in strength with age. The reason could be the choice of using handgrip for the strength comparisons. Everyone uses their hand constantly and unless there were a debilitating illness, such as arthritis, hand strength would not be expected to decline rapidly.

The extensors of the knee may be more likely to show age differences. Kroll and Clarkson (1978), Larsson and Karlsson (1978), Larsson, Grimby and Karlsson (1979) and Murray, Baldwin, Gardner, Sepic and Downs (1977) made dynamic and some static

TABLE 8. Comparisons between results at the approximate ages of 19 and 30

Variable	n	Induction $\bar{X}$	(S.D.)	Follow-up $\bar{X}$	(S.D.)	Difference	p
Age (years)	55	19.38	(0.55)	30.34	(0.85)	+11.00	——
Height (cm)	55	178.00	(5.90)	179.30	(5.80)	+ 1.30	< 0.001
Tibial length (cm)	55	40.20	(2.20)	41.10	(2.60)	+ 0.90	< 0.001
Weight (kg)	55	69.20	(8.60)	76.50	(9.90)	+ 7.30	< 0.001
Femoral condylar breadth (mm)	55	98.20	(4.00)	99.10	(4.30)	+ 0.90	< 0.020
Grip strength right (kp)	55	44.40	(6.50)	48.10	(7.50)	+ 3.70	< 0.001
Grip strength left (kp)	55	40.70	(6.80)	45.30	(7.20)	+ 4.60	< 0.001
Shoulder thrust (kp)	55	63.50	(11.80)	65.90	(12.30)	+ 2.40	> 0.050
Shoulder pull (kp)	54	42.00	(7.70)	45.90	(7.20)	+ 3.90	< 0.001
Skinfold (mm)							
a.	55	9.10	(4.00)	11.40	(4.90)	+ 2.30	< 0.001
b.	55	8.20	(5.20)	10.40	(4.50)	+ 2.30	< 0.020
c.	55	8.80	(5.20)	12.40	(6.30)	+ 3.60	< 0.001
Chest circumference	48	90.20	(4.70)	97.50	(5.50)	+ 7.30	< 0.001
Waist circumference	49	71.50	(5.10)	84.80	(7.40)	+13.30	< 0.001
Heart rate at rest (recumbent 10 min) (beats/min)	55	68.20	(9.90)	69.10	(11.20)	+ 0.90	> 0.500
Orthostatic heart rate (standing 8 min) (beats/min)	55	90.40	(11.70)	85.90	(12.80)	- 5.00	< 0.025
Systolic blood pressure (recumbent 10 min) (mm Hg)	55	128.00	(11.00)	123.00	(12.00)	- 5.00	< 0.020
Diastolic blood pressure (recumbent 10 min) (mm Hg)	55	76.20	(9.10)	76.80	(9.70)	+ 0.60	> 0.600
Heart volume (ml)	51	794.00	(86.00)	810.00	(124.00)	+16.00	> 0.300
W_{170} (watt)	55	178.00	(26.70)	187.00	(34.10)	+ 8.30	< 0.020
W_{170} weight (watt/kg)	55	2.60	(0.40)	2.48	(0.49)	- 1.30	< 0.025

a. On the back just caudal to the scapula

b. At the axillary border of the pectoralis major muscle at the level of the mammilla

c. On the abdomen in the midclavicular line at umbilical level

Wylind, Scele, and Linroth, 1978

measures on knee extensors. Larsson and Karlsson (1978) used fifty males aged 22-65 years. Their results showed no decrease in endurance as a function of age, but dynamic strength was found to decrease with age. Additionally, a decline in dynamic strength was correlated with a decline in type II fibers (fast twitch) as age increases. Larsson, Grimby and Karlsson (1979) found in their 50-70 year old group a definite decrease in performance on both static and dynamic strength. Subjects aged 11-29 reflected an increase of strength followed by a leveling between 30-49 years of age (Figs. 5 & 6). The results of Murray et al. (1977) agreed with those of Larsson et al. (1979) as Murry's older group, aged 45-65, had performed at 75 - 80% capacity of the younger group, aged 20-35. Kroll and Clarkson (1978) combined activity level with the age factor. Activity was divided into high and low categories within each age group (Table 9). The two age groups were 18-38 and 55-79 years. Kroll and Clarkson (1978) found that while strength decreases with age, this decrease can be hindered by regular physical activity. The older group was still below the younger group in performance and the active older subjects were stronger than the inactive older subjects.

Strength differences due to age can also be found when dynamic and static measures are used on the ankle plantar flexor. Falkel (1978) used three age groups 6-8, 14-16, and 23-28 years (Tables 10 & 11). Again age was seen to affect strength differences since strength was higher for each succesive age group.

Thus far, age can be seen as a real factor when dealing with strength measurements. Overall strength appears to increase with

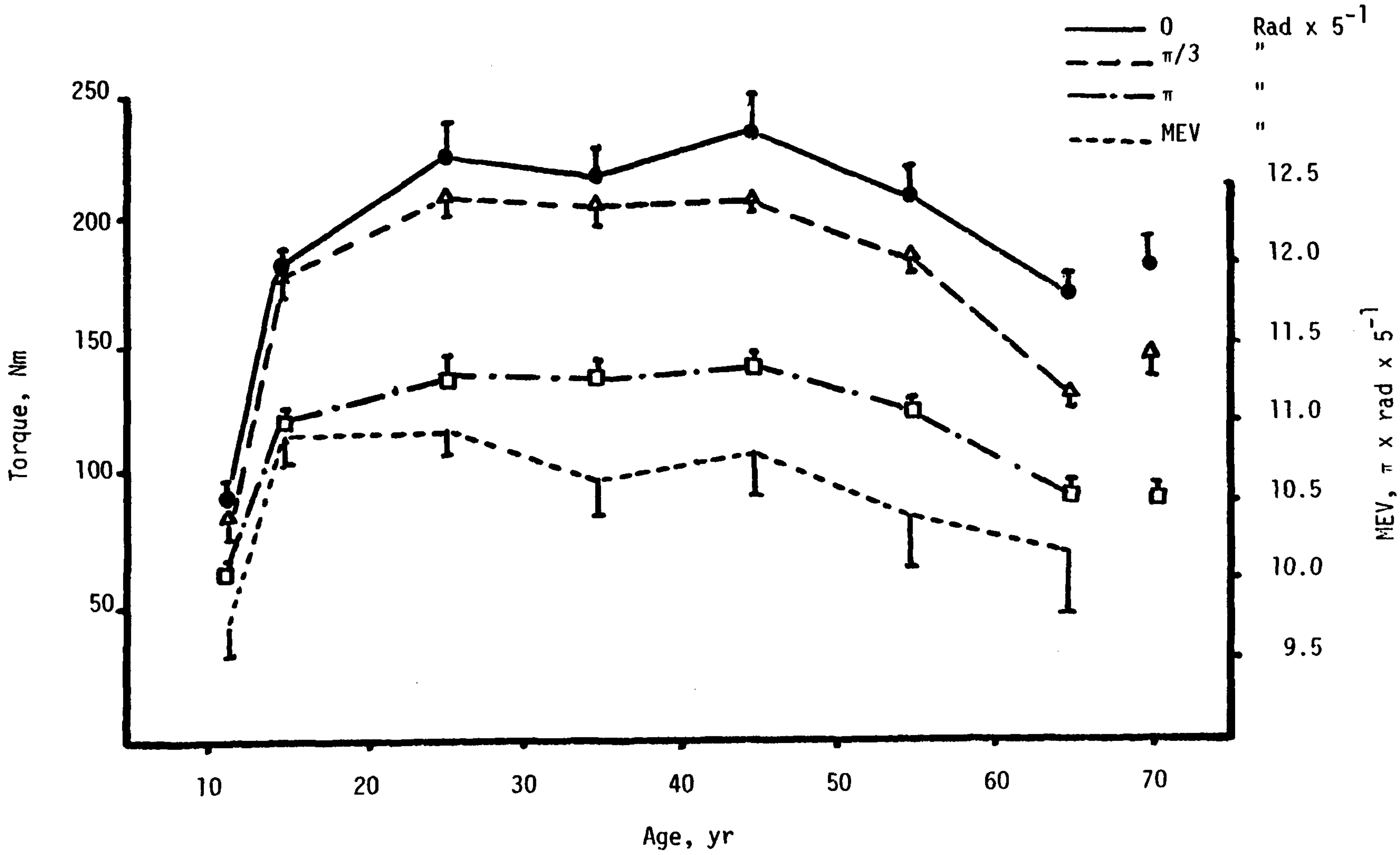

FIGURE 5. Maximum isometric and dynamic strength and knee extension velocity vs. age (Larsson, et al., 1979)

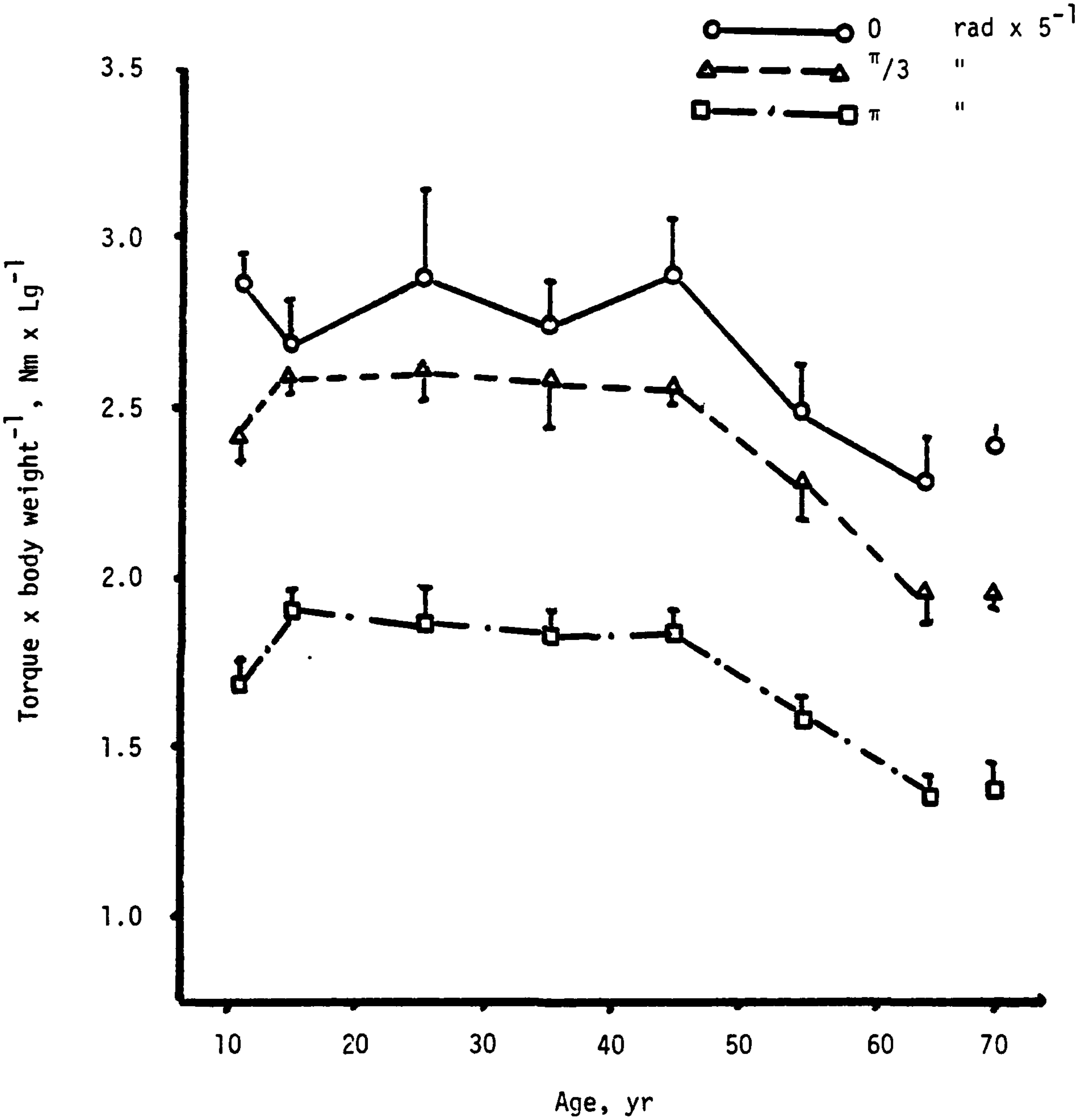

FIGURE 6. Maximum isometric and dynamic strength expressed per Kg body weight vs. age (Larsson et al., 1979)

TABLE 9. Data of old active, old inactive, young active, and young inactive groups

Group	Variable	Mean	Standard Deviation
Old Active (N = 15)	Weight	77.12	8.77
	Height	178.14	6.36
	Age	65.67	6.85
	Triceps Skinfold	9.70	3.51
	Gastrocnemius Skinfold	10.27	4.97
	Subscapular Skinfold	17.40	7.08
	M Skinfold	12.46	2.86
Old Inactive (N = 15)	Weight	84.53	11.71
	Height	180.51	6.33
	Age	63.07	4.35
	Triceps Skinfold	11.23	4.29
	Gastrocnemius Skinfold	9.47	3.48
	Subscapular Skinfold	21.43	6.18
	M Skinfold	14.04	3.59
Young Active (N = 15)	Weight	75.03	10.06
	Height	180.85	5.01
	Age	22.20	3.26
	Triceps Skinfold	5.40	2.50
	Gastrocnemius Skinfold	7.20	3.19
	Subscapular Skinfold	9.37	2.92
	M Skinfold	7.32	2.09
Young Inactive (N = 15)	Weight	76.70	7.52
	Height	177.29	6.01
	Age	21.87	2.10
	Triceps Skinfold	10.67	3.74
	Gastrocnemius Skinfold	13.33	5.59
	Subscapular Skinfold	16.33	6.36
	M Skinfold	13.45	4.57

Kroll and Clarkson 1978

TABLE 10. Isokinetic values by age-sex groups

Age-Sex Group*	SD	Mean (ft lbs)	Median (ft lbs)	Ranges (ft lbs)
6 - 8 boys	± 2.58	6.60	5.75	4.00 - 13.30
6 - 8 girls	± 16.30	11.39	7.45	3.30 - 8.01
14 - 16 boys	± 9.42	26.46	24.10	12.60 - 40.60
14 - 16 girls	± 7.21	25.08	24.00	14.00 - 36.30
23 - 28 men	± 11.37	52.43	50.85	23.60 - 78.40
23 - 28 women	± 8.32	33.31	31.00	21.40 - 50.90

* n = 20 in each group

Falkel, 1978

TABLE 11. Isometric Values by age-sex groups

Age-Sex Group*	SD	Mean (ft lbs)	Median (ft lbs)	Ranges (ft lbs)
6 - 8 boys	± 7.44	12.30	11.00	4.00 - 32.00
6 - 8 girls	± 4.83	11.03	12.20	3.00 - 20.00
14 - 16 boys	± 12.20	39.30	40.40	21.00 - 62.00
14 - 16 girls	± 10.50	35.65	36.50	10.00 - 50.00
23 - 28 men	± 17.00	63.88	65.65	28.00 - 90.00
23 - 28 women	± 12.30	42.40	41.30	22.60 - 66.00

* n = 20 in each groups.

Falkel, 1978

age up to approximately the age of 30-39, a leveling of strength occurs and finally, beginnning approximately at the age of 50, strength starts to decrease.

Sex

Another variable affecting strength is sex. Mortimer (1974) used 599 male and female subjects aged 16-89 to determine the range of foot forces which are exerted by U. S. drivers. Males were found to exert more force than females. Mortimer's (1974) study and several others (Amussen and Heeboll-Nielsen, 1961; Nordgren, 1972; Troup and Chapman, 1969; and Williams and Stutzman, 1958) were covered in a review of sex differences in strength by Laubach (1976). Laubach (1976) noted that usually college age subjects were studied and women performed at lower strengths than men. The upper body, lower body, trunk and total body strength for women was 35-70%, 57-86%, 37-70% and 35-86% of the strength of men respectively (Figure 7).

The same year Lamphiear and Montoye (1976) developed a prediction model for male and female strength performance. They used arm and grip strength as related to anthropometric measures. In additional studies Kamon and Goldfuss (1978); Patton, Hinson, Arnold and Lessard, 1978; and Poulsen, 1978) have all supported Laubach's (1976) review findings. Patton et al. (1978) found that the rate of fatigue was different not only for sex but also for high and low strength differences. Poulsen's (1978) study indicated a relationship exists between back strength and the maximum load lifted since they correlated from .7 to .8. The review by Ayoub, Grasley, and Bethea (1978) of sex differences in

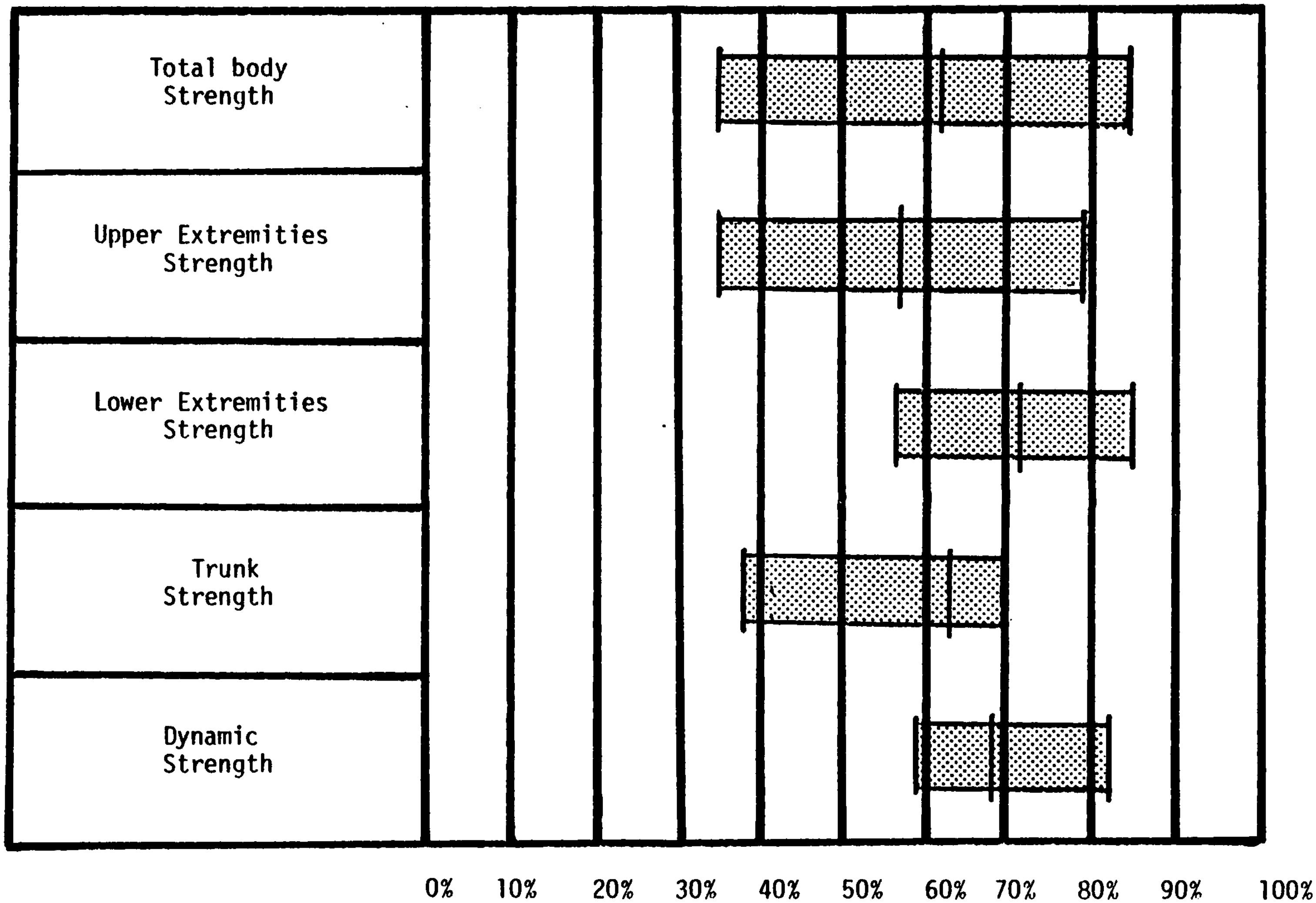

FIGURE 7. The range and mean percentage differences in muscle strength characteristics between women and men (Laubach, 1976)

the literature covered anthropometry, biomechanics and physiological responses. The authors stress the need for future research as the literature thus far is unable to support any ruling based on sex alone.

Age and Sex

Several studies can be found which deal with both age and sex. The Kamon and Golduss (1978) study mentioned above, included two age groups: one of 31 years and below and another of 31 years and above. They found younger women were stronger than the older women in back extension, but had the same strength in back flexion and hand grip. Thus, the results of the hand grip agree with those mentioned earlier for men regarding age. Males were also found to be stronger than women. Isometric strength and body fat appeared to be inversely related to age. The age and sex differences were also upheld by the Montoye and Lamphiear (1977) study using 6,508 subjects (82% of a town's population). A study which also used a large subject pool was Asmussen and Heeboll-Nielsen (1961) when 360 males (ages 15-65) and 250 females (ages 15-55) were used. Their findings were consistent with the results of both age and sex differences obtained by others. Women were found to have only 58% to 66% of the strength of men, even correcting for height the strength of women is still only 70% to 80% of men (Figure 8). They also compared height and weight for their subjects. If height is selected as a predictor, women should have 92% of the strength of men, a prediction not supported by the data collected (Figure 9).

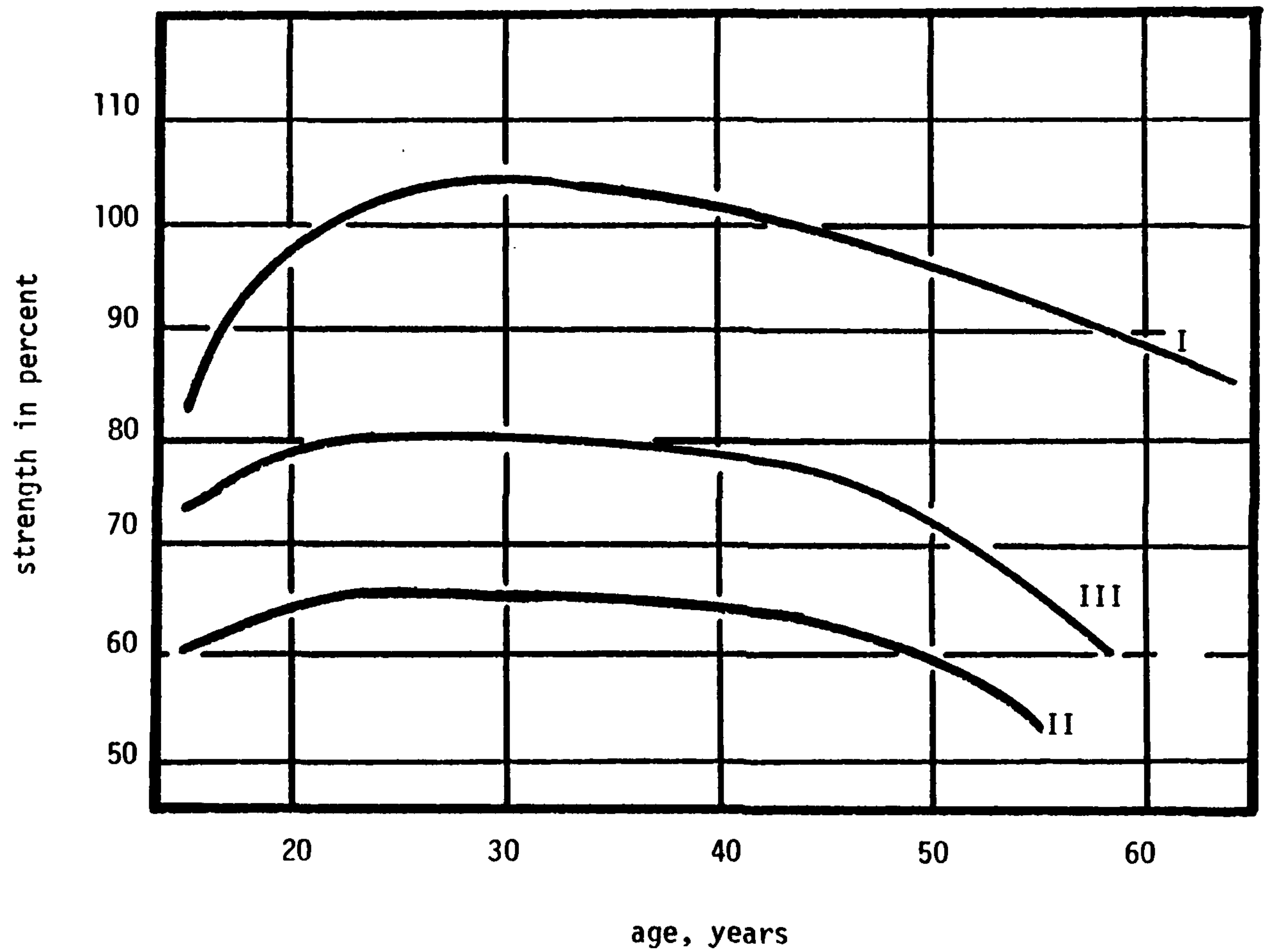

FIGURE 8. Isometric strength in percent of strength of 20-22 year old men in relation to age.
I males, II females, III females, corrected for height
(Asmussen and Heeboll-Nielsen, 1961)

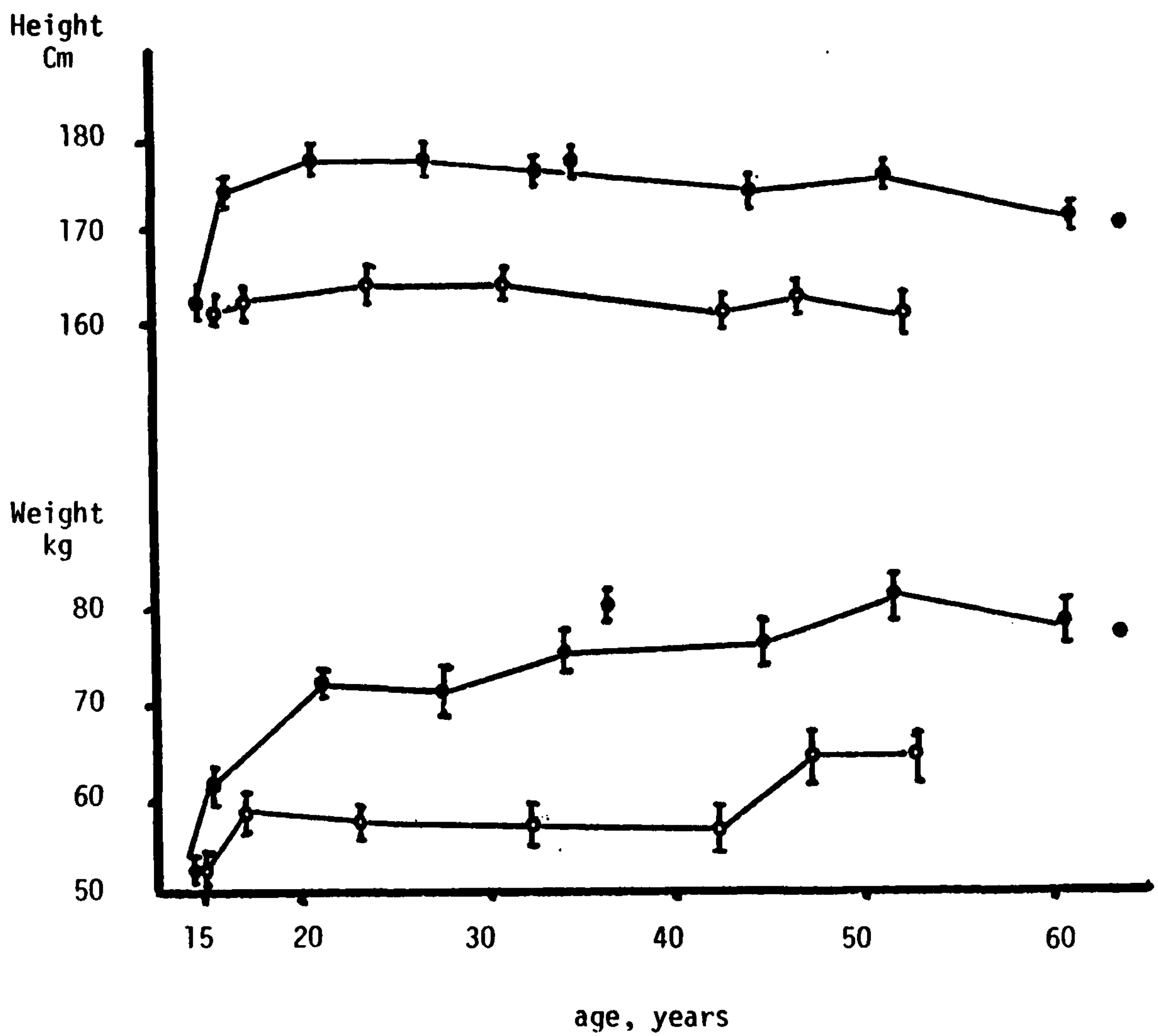

FIGURE 9. Average height and weight in relationship to age vertical lines represent one standard error. (Asmussen and Heebøll-Nielson, 1961)

Testing Procedures

Standardization of methodology is very important. When different methods are used, it becomes difficult, if not impossible, to compare the resulting data. Following are testing procedures to be used in static and dynamic measurements. These procedures cover the areas of measurement protocol, subjects, experimental conditions, subject identities, and presentation of the data.

Protocol for Measurement

	STATIC		DYNAMIC
(1)	A maximum steady exertion for a total of 3 seconds should be performed.	(1)	A maximum steady state range of movement at a given speed should be completed.
(2)	The strength score should be taken as the mean or maximum score during the 3 seconds.	(2)	The strength score is a continuous position dependent value. Values at different angular position (or similar other identifiers) should be reported.
(3)	N/A	(3)	Speeds are normally varied to establish the functional relationship between dynamic strength and speed of movement.

Subjects

STATIC	DYANMIC
(1) Subjects should be screened prior to selection (can be a function of the purpose).	
(2) Subject is usually instructed not to jerk, but to increase exertion to maximum during a 4 or 5 second period.	(2) Subject usually instructed not to jerk but "pick up" the instrument and apply maximum force during the prescribed movement range.

(3) Provide qualitative feedback to the subject about their general performance. Elicit any comments about any problems he/she may have experienced.

(4) Rewards and/or competitive incentives change levels of motivation biasing the strength scores and therefore should be avoided.

(5) Rest periods should be provided. These rest periods should not be less than 2 minutes.

Experimental Conditions

(1) Describe the segment of the body involved (or the muscles involved). Describe the movement (flexion, extension, abduction, ..., etc.).

(2) For activities related to outer space, the level of gravity should be also described.

(3) Body posture assumed should be described. Is the subject sitting, standing, prone, supine, ..., etc.

(4) If the subject is restrained, the experimentor should describe it.

(5) The device or equipment used should be fully described with particular reference to how the coupling between the subject and the device is accomplished.

Subject Identifiers

(1) The sample size, the population it represents and how the sample was stratified should be reported.

(2) If any screening of subjects was made, the criterion or criteria used for screening should be reported.

(3) Sex and age of the subject, height and weight, or other characteristics of interest for the study (body build, lean body mass, ethnic origin, ... etc.) should be reported.

(4) Any training received relating to strength prior to testing should be discussed.

Data Presentation

(1) Generally, the mean and standard deviation are reported. Median and mode occasionally reported. Fifth, 50th, and 95th percentiles are occasionally reported.

(2) The underlying distribution should be reported if known. If assumed normal, this should also be identified. Skewness should be also reported.

(3) Minimum and maximum values should also be reported.

A Consideration In Selecting Data for Analysis

One procedure involved in strength testing which varies among tests is the manner in which the subject's representative score is determined. Some investigators select the best score

while others use the average of several trials. Berger and Sweney (1965) and McCraw and Talbert (1952) report that reliability coefficients change if best scores are correlated rather than average scores. Henry (1967) and Jones (1972) dispute this however.

Summary

The literature is in agreement that muscle strength is increased by training. There is not agreement, however, on the relative benefits of isokinetic versus static training. Some researchers find no difference in strength improvements due to the method of training while others report that isokinetic procedures are better. Part of this controversy may be a bias imposed by the methods used to assess improvements.

The effect of body composition on muscle strength has been a fairly recent topic of study, particularly with regard to athletic performance. The relative area and percentage of fast twitch fibers are related to force output and high speed of contraction. Endurance atheletes have a predominance of slow twitch fibers. With aging, the proportion of fast twitch fibers decreases while slow twitch muscles increase.

Muscular endurance can be defined in terms of dynamic or static muscle contractions. Dynamic endurance in terms of isotonic contractions has primarily been studied. (With the development of an isokinetic testing apparatus, research in this area is being initiated.) Isotonic endurance has been correlated with isometric strength. Attempts to correlate it with isotonic strength have met with mixed success.

Several indices have been developed for assessing isometric endurance but there is no agreement as to which is best. Both positive and negative correlations between strength and endurance have been found depending on whether absolute or relative endurance is studied. The factors felt to be responsible for muscular fatigue include occlusion of muscle blood flow and the build up of metabolic waste products.

The literature was found to be very consistent with regard to age and sex. Females do not have the same strength capacity as males. Mean strength of males is higher than that of females. However, there is considerable overlap of the ranges. In addition, the difference between means is not constant but a function of the muscle group utilized. Strength is seen to increase with age during childhood, level off during middle age, and decline after age 50. The rate of decline is related to the level of physical activity.

The dynamic strength on an individual is affected by both environmental and psychological factors such as noise, hypnosis, and drugs. Power exerted is related to muscle tension and length and to the physical fitness of the individual. Torque decreases as the speed of contraction increases.

The literature surveyed reflected a great deal of work on static measures using several different muscle groups. Static strength is influenced by environmental temperature, testing instructions, muscle length, and the muscle group tested. The recovery from maximum exertion can take up to four hours with low strength groups recovering faster than high strength groups.

METHODS AND PROCEDURES

Subjects

In order to determine an Atlas of Strength for males, a sample consisting of 25 male subjects was selected. The subjects were drawn from the campus of Texas Tech University. Subjects were recruited through advertisement in the University paper. This advertisement described the work as requiring strength measurements. Basic height and weight restrictions given in Appendix 1 were listed as a prerequisite for participation. Subjects responding to the advertisement were interviewed and the nature, demands, and actual tasks were demonstrated and any questions answered. Subjects who met the height and weight criteria and were still interested in participation following the interview, were then sent to the University Health Services for a physical examination. Subjects passing this examination were then used as experimental subjects.

Apparatus

All strength measurements were made using the Cybex II Isokinetic apparatus (mfg. by Cybex Div. of Lymex, Inc., Serial No. C-30370), shown in Figure 10. This apparatus consists of a dynamometer and goniometer that picks up the limb produced torque and angle of motion and then transmits an electrical signal to a two channel strip chart recorder. One channel records torque in foot-pounds and the other channel records degrees of rotation of the specific joint. Used in conjunction with the Cybex measuring and recording equipment was a padded top Upper Body Exercise and

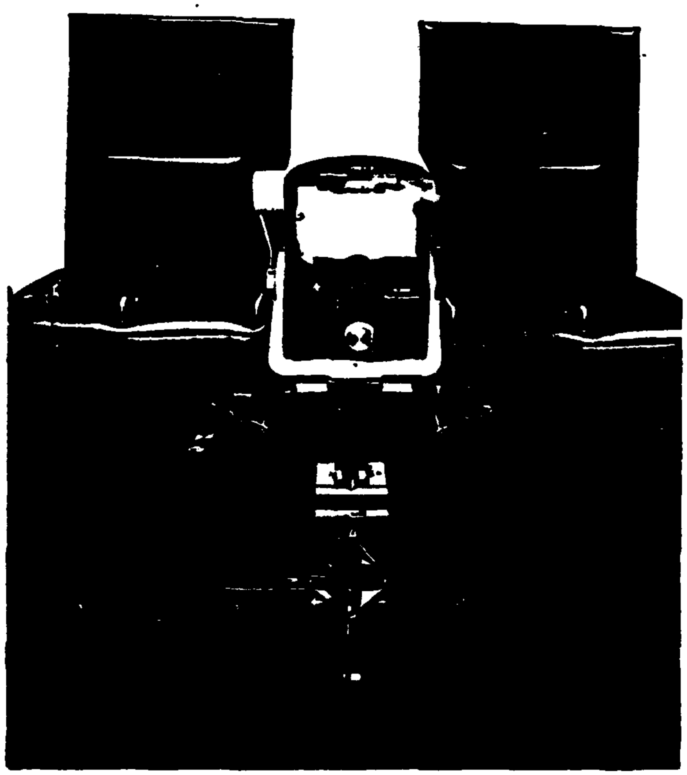

FIGURE 10. Cybex II isokinetic apparatus

Testing Table (UBXT) built by Cybex (see Figure 11). This bench has a back rest which is adjustable to either a horizontal position or an approximately 45° inclined position. This padded top bench was used in the measurement of the following body segment rotation joints:

a. Elbow

b. Shoulder (Proximal Humerous)

c. Hip (Proximal Femur).

The UBXT has a brake that is used to prevent slipping, however when the torque exerted was large, there was still a possibility of slipping. For this reason, a carpet was installed on the floor and weights added to the UBXT frame.

A chair having an adjustable vertical height and a seat pan that can be rotated horizontally through different angles were used in the measurements to obtain all torques at the knee. This chair was designed and constructed at Texas Tech University and is shown in Figures 12 and 13.

A special metal arm designed and constructed by Texas Tech personnel was used in measurement of torques associated with the extension of the lower back (Figure 14). This arm attaches to the dynamometer head and extends upward and parallel to the face of the dynamometer. The upper end of the arm is forked. At the end of each fork, a roller extends perpendicular to the fork. In lower back measurements, the subject places himself between the rollers with one roller in contact with the his chest and the other roller making contact with the back. The distance between

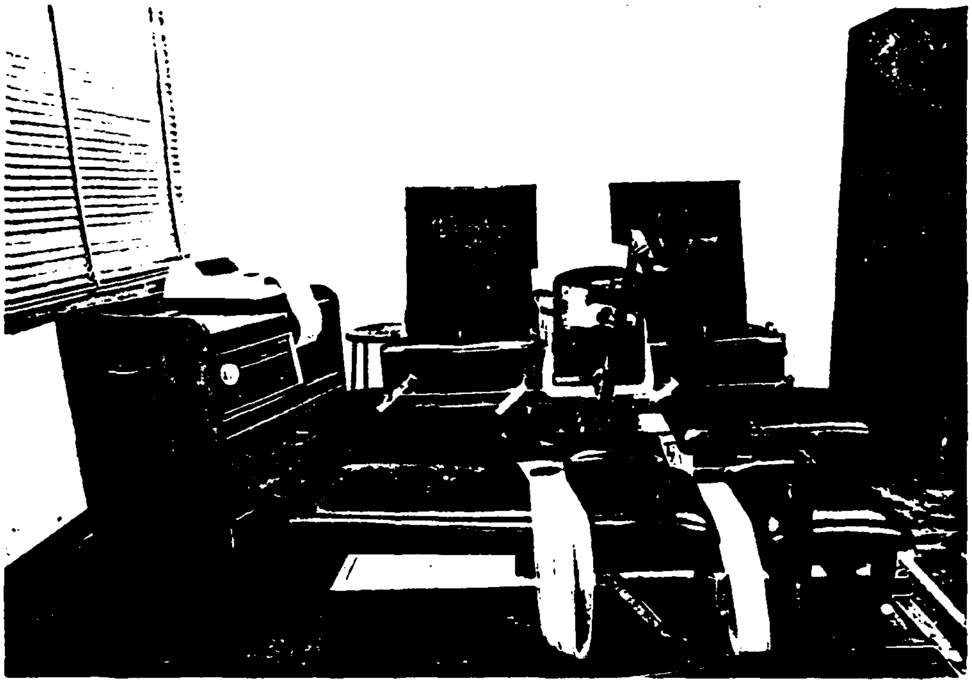

FIGURE 11. Cybex II isokinetic apparatus with upper body exercise and testing table (UBXT)

FIGURE 12. Chair used in measuring torques at the knee set in the 0° rotation position

FIGURE 13. Chair used in measuring torques at the knee set in the -30° rotation position

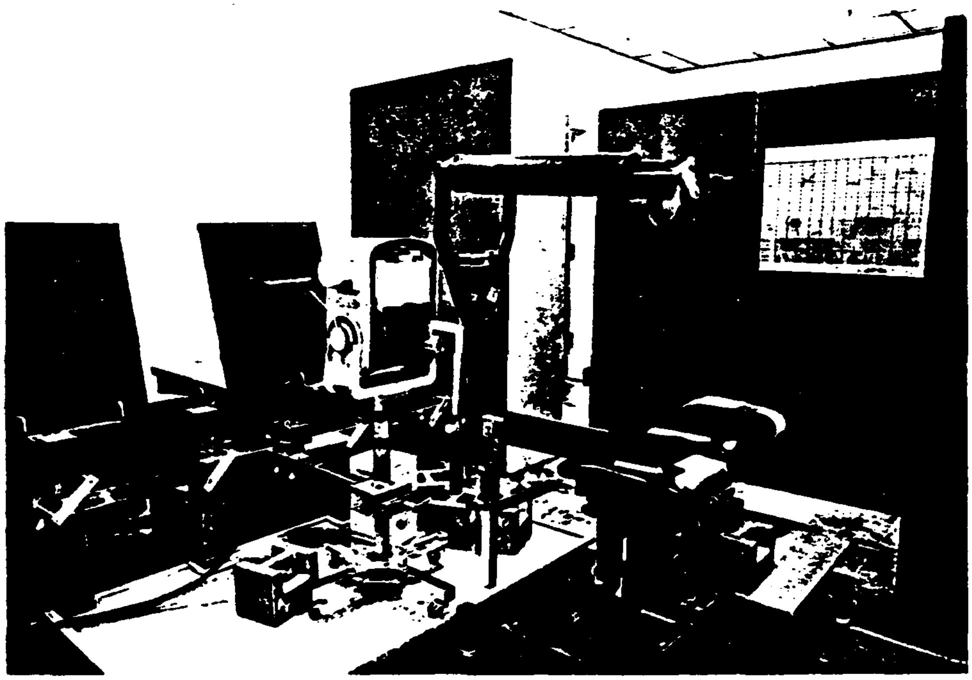

FIGURE 14. Cybex II isokinetic apparatus with the attachment for measuring back strength

the rollers is adjustable to accomodate subjects with different chest depths.

Used in conjunction with all of the above equipment was a wooden platform designed and constructed in the Texas Tech shops. It was used to stabilize and to give extra height to the Cybex dynamometer and goniometer during shoulder, elbow, and back measurements, and also to give extra subject height for hip, shoulder and elbow measurements at different angles of joint rotation. The platform 's shown in Figure 15.

General Procedure

Before any testing began, subjects were required to present documentation indicating that a complete health examination had been taken and passed. After this documentation had been gathered, the test subjects were informed in detail of the type of testing to be performed and how it would be accomplished. The subject would then fill out an additional Health Screening consent form given in Appendix 2.

All strength tests were performed in the Ergonomics Labs housed in the Texas Tech Industrial Engineering building. The lab temperature was 68° ± 5°F. Room pressure and humidity were not controlled. Atmospheric conditions at the time of the test prevailed.

All test subjects were required to wear loose clothing (i.e., sweat pants and shirt) during testing, and specifically shorts when either the knee or the hip joints were tested.

All strength measurements on the arm or leg were made using the unpreferred limb, that is to say, all right handed subjects were tested using their left arm and leg, and vice versa.

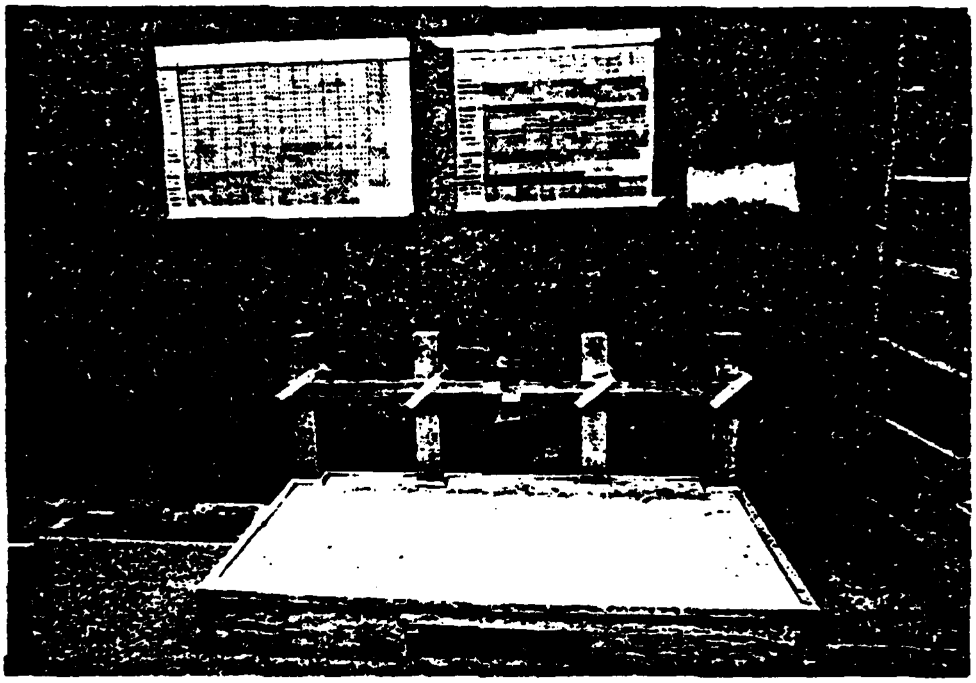

FIGURE 15. Wooden platform used with Cybex II isometric apparatus

Strength measurements were taken at the following body joints: elbow, shoulder, lower back, hip, and knee. Each of these five joints were tested for static strength and dynamic strength at three dynamometer speeds; 0 rpm, (static); 5 rpm, and 25 rpm. The torque exertions occurred at different starting angles relative to the anatomical zero position of the limb. For static measurements, the position at which the torque was exerted was defined as starting angle or starting position even though the applied force did not cause any motion. For dynamic measurements, the torque was exerted from the starting position of interest until reaching the specified limit for the range of motion. The range limit used for the elbow and shoulder measurements was 120° and a range limit of 90° was used for the back, hip, and knee measurement.

Five planes of motion were defined for those joints operating in the sagittal plane; elbow, vertical flexion of the shoulder, hip, and knee. Abduction of the shoulder and horizonal flexion of the shoulder were excluded as these two limb movements do not occur in the sagittal plane. The lower back was excluded to avoid possible injury to the subjects since no equipment design was available which would allow measurement away from the sagittal plane without the risk of injury.

The five planes are described as angles of rotation away from the sagittal plane in the transverse plane. Motion in the sagittal plane was considered to be 0° rotation. The two planes defined by rotating 15° and 30° medially from the sagittal plane were considered positive rotations. When the rotation was made

laterally, again 15° and 30°, from the sagittal plane, the rotation was considered negative (Figure 16).

Before each measurement, the apparatus was set up, and the appropriate attachment used for the transmission of the torque was attached to the dynamometer. The subject was then placed in the appropriate position and the axis of rotation of the joint of interest was aligned with the axis of rotation of the dynamometer. The subject was then strapped in position, whenever applicable, and the limb was attached to the testing arm.

Each test subject applied force in the same manner. Subject position in relation to test equipment is given in the section on specific procedures. The test administrator described in detail the method in which the force was to be applied by each test subject and then observed that these instructions were followed. The method of force application followed the steps listed below:

1. Administrator asked subject if he was "ready" to apply force.
2. When the subject was ready, the administrator stated "chart on". This statement indicated that the test equipment was recording and that the administrator was waiting for the subject to exert a torque.
   a. For dynamic testing, the administrator monitored the position or degree read-out channel of the strip chart recorder. When the desired angle of sweep had been reached, the administrator would then say "stop".

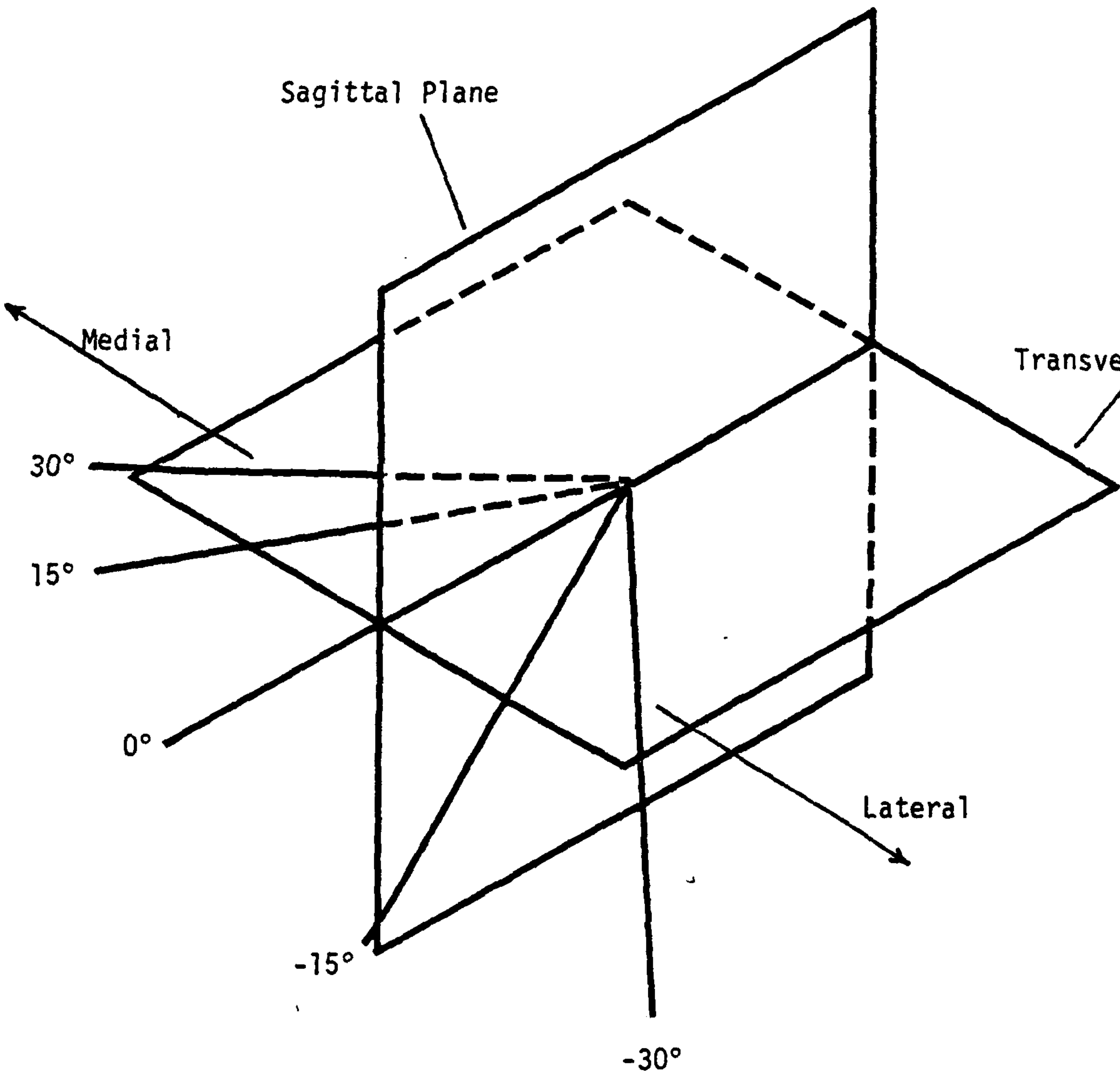

FIGURE 16. Angles of rotation

b. For static testing the administrator monitored the force read-out on the torque channel of the strip chart recorder. When a maximum force was reached and maintained for approximately 4 seconds the administrator would then say "stop".

In the dynamic sweep measures, subjects were told to exert maximum force over the range of movement and continue until the administrator instructed him to stop. For static strength measures, the subjects were to gradually build up to maximum force and sustain that level until told to stop.

For all strength tests, three measures were taken at each specified combination of joint, angle of rotation, speed, and starting angle. The three measures were taken at one time with a short rest between them, usually one to two minutes depending on the subject. As shown in Table 12 not all joints were tested at all possible combinations of the variables. Only the elbow and shoulder vertical flexion and extension were tested for all five angles of rotation. The hip and knee were tested for the negative angles of rotation, while the abduction of the shoulder, horizontal flexion of the shoulder and lower back were tested only in the sagittal plane or 0° rotation.

Because the hip and knee were measured for extension and the 0° degree position was defined by full extension of the limb, no measures of strength were made at the 0° degree starting position. The measurement of the back was also an extension measure, but unlike the hip and knee, hyperextension of the back was

TABLE 12. Measured combinations of joint, rotation[1], speed and starting angle

Joint	Rotation (DEG)	SPEED (RPM)	STARTING ANGLE (DEG)	MAXIMUM RANGE OF MOTION (DEG)
Knee (KNE)	-30, -15, 0	0, 5, 25	30, 60, 90	90 - 0
Hip (HIP)	-30, -15, 0	0, 5, 25	30, 60, 90	90 - 0
Back (BAC)	0	0, 5, 25	0, 30, 60, 90[2]	90 - 0
Vertical Flexion of Shoulder (VFE)	-30, -15, 0 15, 30	0, 5, 25	0, 30, 60, 90	0 - 120
Horizontal Flexion of Shoulder (HFE)	0	0, 5, 25	0, 30, 60, 90	0 - 120
Abduction of Shoulder (ABD)	0	0, 5, 25	0, 30, 60, 90	0 - 120
Elbow (ELB)	-30, -15, 0 15, 30	0, 5, 25	0, 30, 60, 90	0 - 120

[1]See text for definition of the variable rotation

[2]The 0° starting position was for the static condition only

possible allowing a static measure to be obtained for the back at the 0° starting angle.

A set was defined as three repetitions of a specific combination of joint, rotation angle, speed, and starting angle. A cycle was defined as four sets performed by a single subject before he was released to permit testing of the next subject. A session was the daily period of data collection for the group of subjects under test.

Each group of subjects consisted of either one, two or three subjects. It was preferrable to use more than one subject at each test session whenever possible so that one subject can be tested, then allowed to rest while the remaining subjects were tested in turn. Each team of subjects whether only one, two or three subjects completed the whole set of experiments together, i.e. the team was not changed throughout the experiments. Testing within sessions were scheduled such that joints of interest would not become fatigued. Generally, the first measurement of a test cycle on a joint for zero angles of rotation had a test apparatus set up time of about five minutes, while the first measurement of a test cycle associated with a change in rotation angle other than zero, required about ten minutes of test apparatus set up time. All the measurements in a test cycle were completed in ten to twenty minutes. A period of two to three minutes rest was allowed between each successive measurement contained within a test cycle.

Specific Procedures

The position of the test subject in relation to test equipment is described below.

A. Knee Joint (KNE)

1. The subject was seated on the adjustable vertical height backless chair.
2. The subject's hands grasped the bottom of the chair seat at each side (Figure 17).
3. The axis of the dynamometer was adjusted so that it projected an imaginary line through the lateral side to the medial side of the knee joint through the axis of rotation (Figure 18).
4. The distal part of the lower leg, just above the ankle, was strapped to the appropriate arm attached to the dynamometer head, so that the pad rested on the anterior side of the leg, and the strap on the posterior side.
5. The 0° baseline at the bottom of the position angle channel was adjusted when the subject was positioned at the anatomical zero position, i.e. with the leg extended horizontally.
6. For negative limb rotation angles, the tested leg remained in the same position as for 0° rotation, while the rest of the body was rotated (by rotating chair seat) through the designated angle, effectively rotating the hip (Figure 19).
7. The type of movement was extension of the limb.

FIGURE 17. Extension of knee at 0° rotation

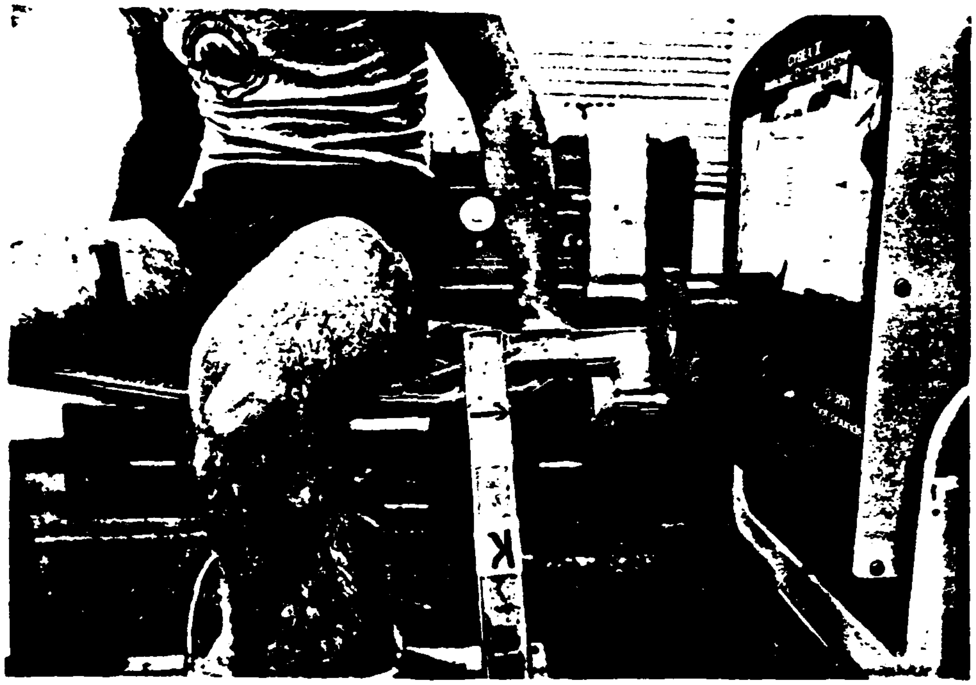

FIGURE 18. Alignment of knee joint with dynamometer axis of rotation

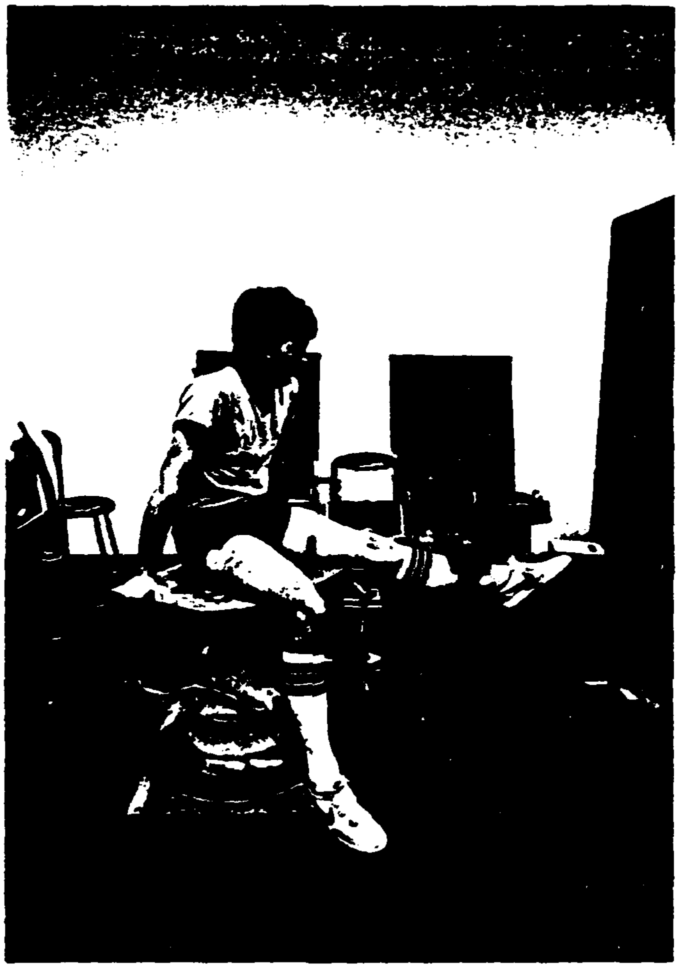

FIGURE 19. Extension of knee at -30° rotation

B. Hip Joint (HIP)

1. The subject was instructed to lie in a supine position on the UBXT padded table.
2. The hip joint was aligned with the axis of rotation of the dynamometer so that an extended imaginary line passed through the hip pivotal point.
3. The lower and upper part of the subject's trunk was strapped to the UBXT table.
4. The dynamometer arm was attached just above the knee. The pad rested on the anterior side of the leg, while the strap surrounded the leg from the posterior side.
5. The 0° baseline at the bottom of the position angle channel was adjusted when the subject was positioned at the anatomical zero position, i.e. with the leg resting horizontally on the UBXT (No hyperextension of the hip was possible due to the table being under the upper leg).
6. The subject's hands grasped the columns supporting the surface of the UBXT on which the subject reclined, one on each side almost below the subject's hip joints.
7. The tested leg was allowed to bend during movement.
8. The other leg was hanging over the end of the UBXT (Figure 20).
9. Negative limb rotation angles were adjusted by rotating the head of the dynamometer upwards about

FIGURE 20. Extension of hip at 0° rotation

its horizontal axis while the tested leg always remained in the same position on the UBXT which was placed on the wooden platform to adjust the height of the joint for this position (Figures 21, 22).

10. The type of movement was extension of the limb.

C. Back (BAC)

1. The subject was in a standing position.
2. The subject's arms were hanging straight beside trunk or clasped behind the back.
3. The dynamometer axis was adjusted to the pivotal point at the hip.
4. The subject was positioned between the rollers on the forked arm. The forked arm was rigidly attached to the dynamometer head (Figure 23).
5. The rollers were adjusted so that they touched the subject's chest and back at armpit height.
6. The UBXT was placed in front of the standing subject and an arm was attached to it so that it touched the upper part of the thighs horizontally providing the subject support as he bent down.
7. A heavy metal block was placed behind the subject's heels to stabilize his position.
8. The 0° baseline of the position angle channel was adjusted when the subject was positioned at the anatomical zero position i.e. standing erect.
9. Only movement in the sagital plane was measured.

FIGURE 21. Extension of hip at -30° rotation

FIGURE 22. Extension of hip showing use of wooden platform for negative angles of rotation

FIGURE 23. Extension of the back

10. The type of movement was extension in the sagittal plane.

11. For the dynamic measurements, the subject was asked to start exerting the force from the starting position (90°, 60° or 30°) and continue exerting the force past the zero position. One of the experimenters stood behind the subject to stop him at about -30° (Figure 24).

D. Shoulder Joint (Vertical Flexion - VFE)

1. The subject was stretched in a supine position on the UBXT table with the body straight and his arm parallel to the longitudiual axis of the body.

2. The dynamometer axis was adjusted at the axis of rotation of the shoulder joint.

3. The body was strapped across the lower trunk as far as possible towards the legs and across the chest as far as possible towards the armpits without interfering with the motion of the arm.

4. The tested arm was kept straight throughout all the movements.

5. The hand of the tested arm was half-way between the supinated and pronated position while gripping the handle on the dynamometer arm.

6. The untested hand gripped a stabilizing handle at the side of the UBXT table (Figure 25).

7. The 0° baseline of the position angle channel was adjusted when the subject was positioned at the anatomical

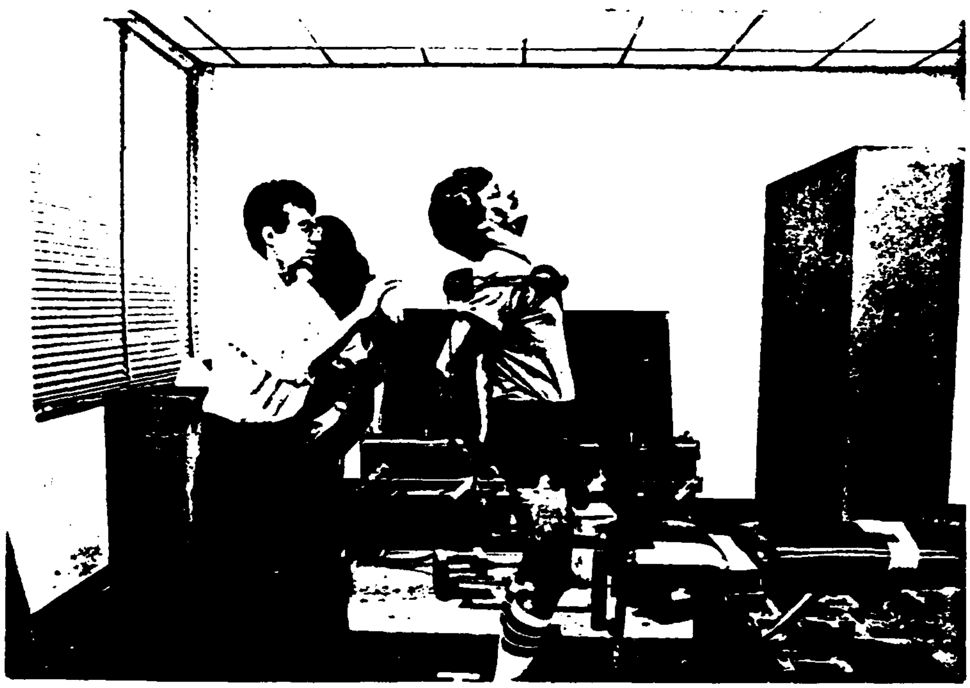

FIGURE 24. Extension of the back showing experimentor in position to "catch" the subject

FIGURE 25. Vertical flexion of the shoulder at 0° rotation

zero position, i.e. the arm was straight by the side.

8. The dynamometer head was tilted on its horizontal axis to achieve the various limb rotation angles, and the wooden platform was used to raise the dynamometer for the positive angles of rotation, or the UBXT for the negative angles of rotation (Figures 26, 27).

9. The type of movement was flexion of the limb.

E. Shoulder Joint (Horizontal Flexion - HFE)

1. The subject was stretched in a supine position with his arm extended perpendicular to the longitudiual axis of the body.

2. The seat of the UBXT was slightly elevated (to the middle position) if required by the subject to improve his comfort.

3. The dynamometer axis was adjusted parallel to the longitudinal axis of the subject's body and passing through the axis of rotation of the shoulder with the arm in the horizontal position.

4. The body was strapped across the lower trunk as far as possible towards the legs and across the chest as far as possible towards the armpits without interfering with the motion of the arm.

5. The hand of the tested arm was halfway between the supinated and pronated position while gripping the dynamometer arm.

FIGURE 26. Vertical flexion of the shoulder at 30° rotation

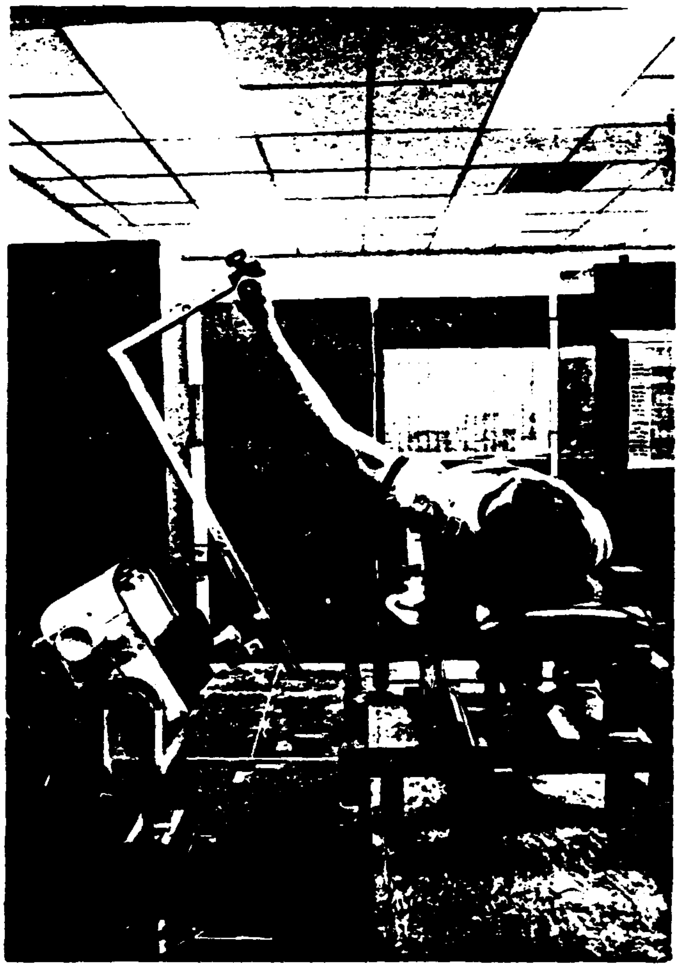

FIGURE 27. Vertical flexion of the shoulder at -30° rotation

6. The tested arm was kept straight throughout all the movements.
7. The untested hand gripped a stabilizing handle at the side of the UBXT.
8. The 0° baseline of the position angle channel was adjusted with the arm stretched horizontally (Figures 28, 29).
9. The type of movement was flexion of the arm.

F. Shoulder Joint (Abduction - ABD)

1. The UBXT backrest was adjusted to the highest position and the seat to the middle position. The subject was then in a semi reclining position with the legs slightly raised and his feet on the footrest.
2. The dynamometer head was tilted back 40°.
3. The dynamometer axis of rotation was aligned with the joint axis of rotation.
4. The body was strapped across the lower trunk and the chest (Figure 30).
5. The tested arm was kept straight throughout the movement.
6. The untested hand gripped a stabilizing handle at the side of the UBXT (Figure 31).
7. A safety cushion was placed at the lower starting position to block the shoulder testing accessory tube.
8. The 0° baseline of the position angle channel was adjusted with the arm by the side extended downwards

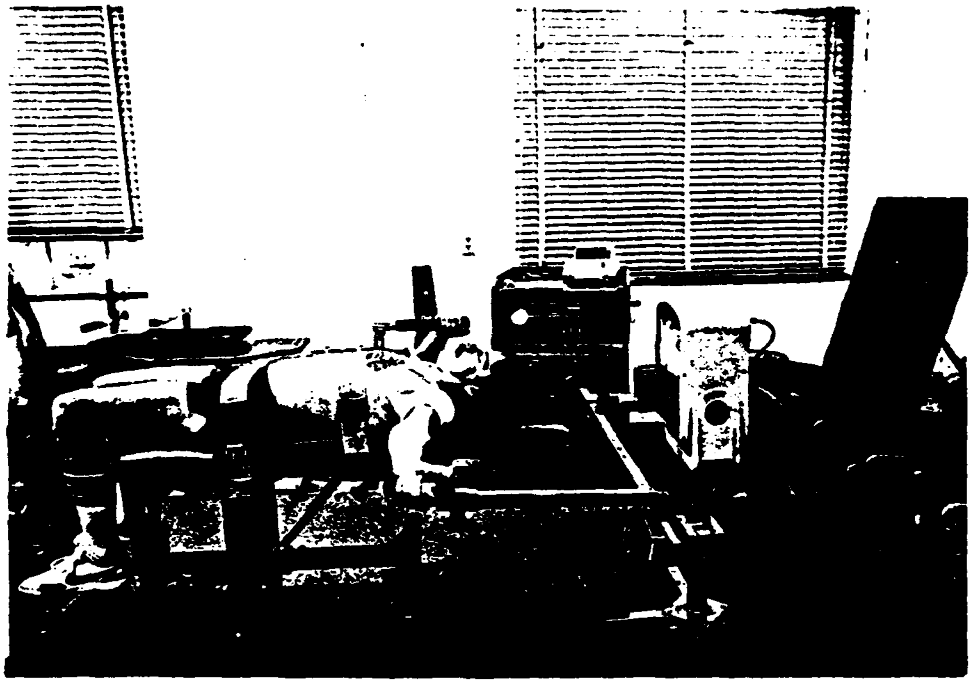

FIGURE 28. Horizontal flexion of the shoulder at 0° starting angle

FIGURE 29. Horizontal flexion of the shoulder at 60° starting angle

FIGURE 30. Abduction of the shoulder at 0° starting position

FIGURE 31. Abduction of the shoulder at 30° starting angle

9. Limb movement occurred in the frontal plane.

G. <u>Elbow Joint (ELB)</u>

1. The subject stretched in a supine body position on the UBXT table with the arm to be tested parallel to the longitudal axis of the body and a pad supporting the arm under the elbow.
2. The dynamometer axis was adjusted to the axis of rotation of the elbow.
3. The subject's body was strapped at the lower trunk and chest as in case of the shoulder joint.
4. The upper arm was held at a constant position as much as possible parallel to the longitudinal axis of the body.
5. Movement of the shoulder joint was discouraged.
6. The hand was midway between supination and pronation as it gripped the handle of the dynamometer arm.
7. The untested hand gripped a stabilizing handle at the side of the UBXT.
8. The 0° baseline of the position angle channel was adjusted with the lower arm fully extended by the subject's side (Figure 32).
9. The dynamometer head was tilted on its horizontal axis with respect to lower arm through the various rotational angles as in the vertical flexion of the shoulder (upper arm considered as one unit with body). Also the dynamometer or the UBXT were placed on the wooden platform as required to obtain the measurements.

FIGURE 32. Flexion of the elbow at 0° rotation

10. The 0° starting angle in case of the positive angles of rotation was maintained using a horizontal pad which was attached to the side of the UBXT. This pad supported the subjects arm and attachment of the dynamometer in the horizontal position. The pad was not used for 0° or negative angles of rotation since the arm and arm attachment were supported in the horizontal position by the edge of the UBXT (Figure 33).

11. The movement was flexion at the elbow. The starting position was established by means of the test administrator holding the limb at the proper angle until the subject began the movement of the limb.

In all the above positions of the subject in relation to the test equipment, the input arm length was adjusted according to the subject's limb length. This length was recorded and used whenever the same joint was tested for the same subject for the remaining movements of that limb.

The different starting angles were determined from the position angle channel of the chart recorder relative to the zero baseline which was set at the beginning of each joint measurement. The experimenter held the subjects limb in the desired starting position until the subject initiated the test movement.

For the back and hip measurements, weight had to be placed on the bottom of the UBXT to stabilize it, since the torques exerted were of large magnitude and slipping of the UBXT on the floor

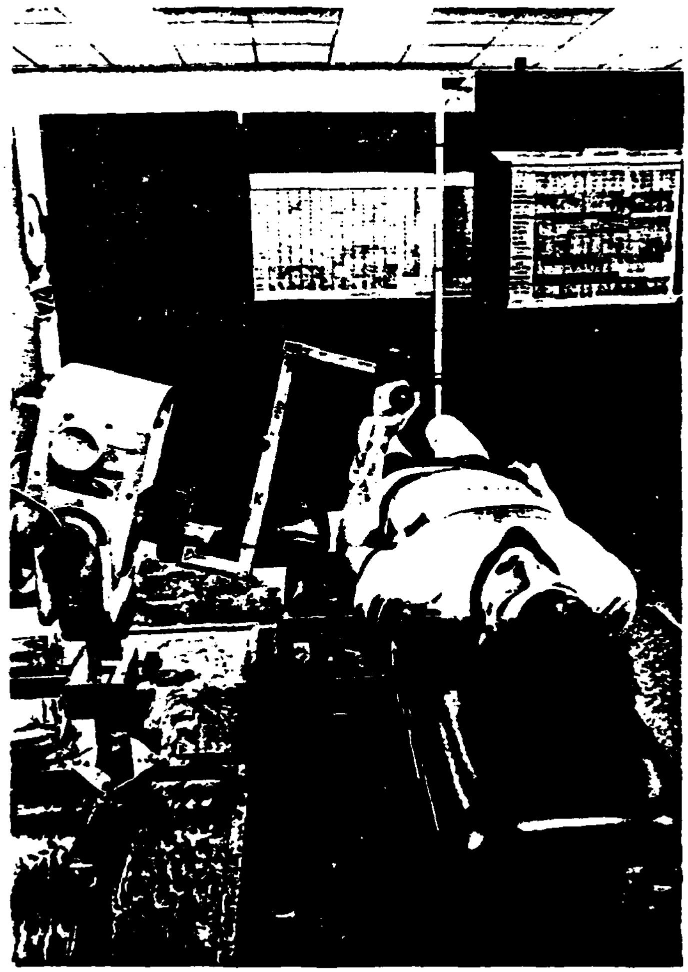

FIGURE 33. Flexion of the elbow at 15° rotation

could have occurred. Weights were also placed on the wooden platform whenever it was used in conjunction with the hip or back measurements to eliminate movement of the platform.

Data Transcription from Chart Paper

The chart paper consists of two parts. The upper part is used for recording torque and the lower part for position angle. The torque side has three range settings; 0 to 30, 0 to 180, or 0 to 360 ft-lbs. The position scale has two range settins; 0° to 150° or 0° to 300° degrees. In this study, all three scale ranges of the torque and only the 0° to 150° range of position scale were used.

For each data set, a stamp was used to facilitate the recording of the labeling information such as date of the experiment, name of the subject, angle of rotation, joint tested, speed, starting angle, and sequence number on the chart paper (Figure 34). The sequence number allowed identification of the temporal relation of a set to the other sets taken during a given session. A sequence number consisted of two digits, for example 43. In this example, the 4 represented this subjects fourth cycle while the three indicated this was the third set of the present cycle.

A "Cybex II Chart Card" was used to interpret the information on the chart paper and to determine the appropriate torque for a specific angle. The card has several grids, A, B, C, D, E (Figure 35). In this study only grids F (30ft-lbs/150° scales), D (180 ft-lbs/150° scales) and B (360 ft-lbs/150° scales) were used. For example grid D was used to interpret the sample data

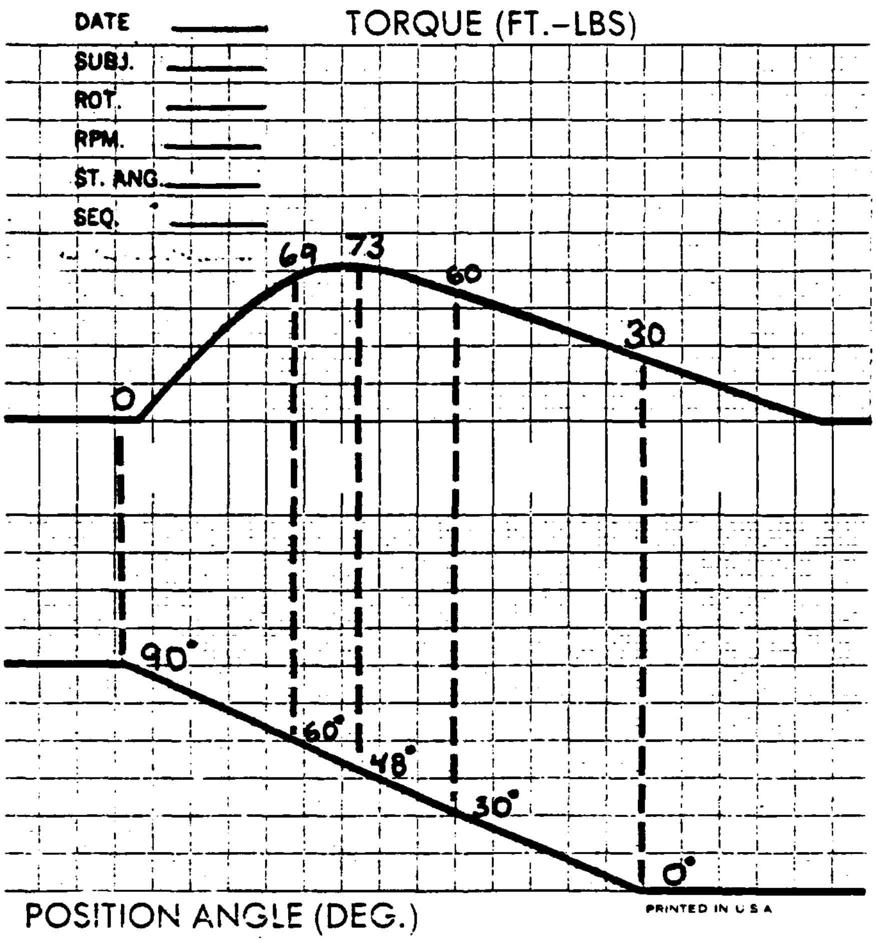

FIGURE 34. Chart paper used with the Cybex II recorder

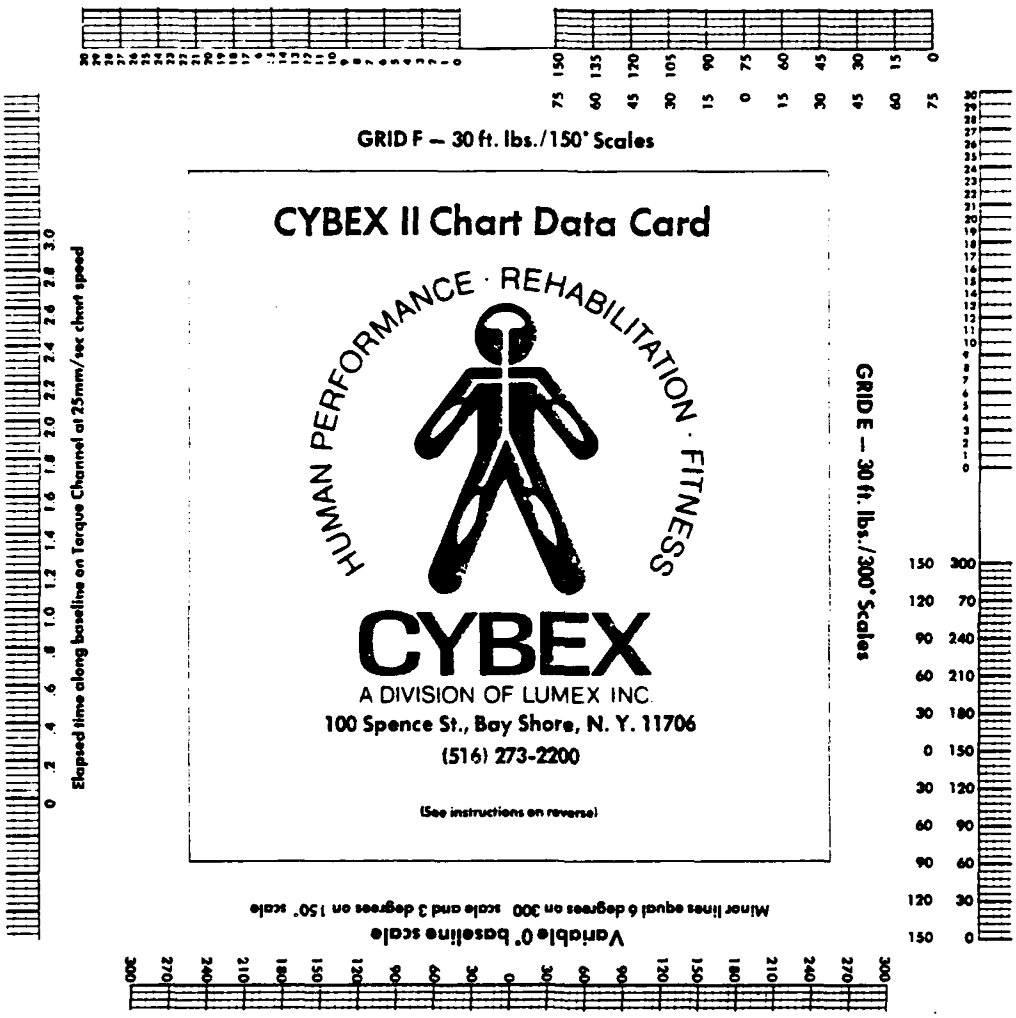

FIGURE 35. Cybex II chart data card (front view)

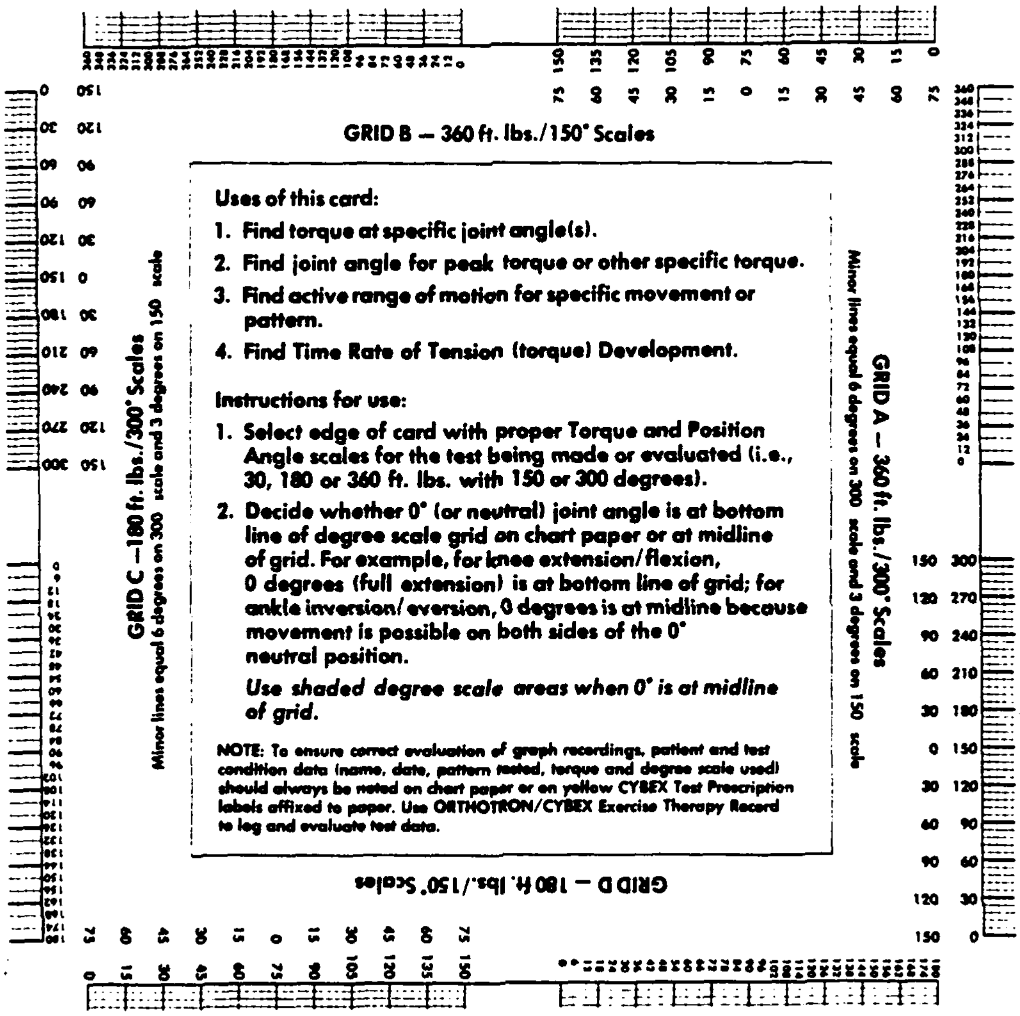

FIGURE 35 CONTINUED. Cybex II chart data card (back view)

in Figure 34. This was accomplished by placing grid D (180 ft-lbs/150° scales) across the chart paper aligning the scale markings and noting the values from the card. The maximum torque of 73 ft-lbs occurred at 48 degrees. The torque at 30 degrees was 60 ft-lbs.

The data were transcribed in the above fashion and noted on the chart paper. Then these were transferred to a coding sheet. An "IBM FORTRAN Coding form" was used as the coding sheet. This form had 80 columns. The columns were assigned as depicted in Table 13. Later the data were transferred by hand from the coding sheet to a computer file to facilitate analysis.

TABLE 13. Format of coding form used for data input into the computer file

IBM

FORTRAN Coding Form

GX28-7327-6 U/M 050
Printed in U.S.A.

FORTRAN STATEMENT

DATE	SUBJECT	ROTATION	JOINT	SPEED	START	MAX	ANGLE
0130	01	R-30	KNE	25	30	23	01
						16	00
						18	00
	01	R-30	KNE	05	30	48	14
						56	11
						53	12
	01	R-30	KNE	25	60	42	12
						35	12
						34	10
	01	R-30	KNE	05	90	102	57
						92	60
						103	60
	02	R-15	HIP	00	30	178	30
						189	30
						140	30
	02	R-15	HIP	05	20	123	10
						123	09
						130	17
	02	R-15	HIP	25	90	124	16
						131	13
						145	22

RESULTS AND DISCUSSION

The data obtained for the static and isokinetic measures are combined in this section. A summary of the data is presented followed by a discussion of the effects each of the independent variables had upon the maximum torque. A correlational analysis of the static and isokinetic torques was performed and the results of that analysis are presented. Also included is a section on the distribution of the anthropometric and strength data. Goodness of fit tests were performed on the strength data and the results of these tests are discussed. Finally an accomodated percentage model is described and a sample of its output presented.

Static and Isokinetic Maximum Torque Data

Since the static and isokinetic data were collected at different speeds on a continuum, the data analysis was performed on the combined data sets. A summary of the data is presented in Table 14.

Most of the variable combinations are based on 75 observations (3 observations each for 25 subjects). Some of the combinations are observed to have fewer than 75 observations. Early in the course of the study, high torques for the hip were observed; torques approaching the upper limit of the measuring equipment being used in the study. Further collection of this type of data was suspended until technical clarification could be obtained, by then the subjects were no longer available to make the missed combinations.

TABLE 14. Summary of strength data

JOINT	ROT	SPEED	START	MAXMN	ANGLEMN	MAXSD	ANGLESD
ABD	RO	0	0	47.933	0.000	13.1152	0.0000
ABD	RO	0	30	36.707	30.000	8.4097	0.0000
ABD	RO	0	60	33.720	60.000	8.4110	0.0000
ABD	RO	0	90	31.773	90.000	8.7774	0.0000
ABD	RO	5	0	32.960	42.213	6.0548	27.3507
ABD	RO	5	30	29.240	70.987	7.7142	20.2954
ABD	RO	5	60	28.707	91.867	6.6409	11.5856
ABD	RO	5	90	28.569	112.875	8.3292	6.7405
ABD	RO	25	0	23.307	88.000	5.5458	18.7660
ABD	RO	25	30	22.917	106.736	4.9412	14.0612
ABD	RO	25	60	20.627	114.813	7.1542	7.3332
ABD	RO	25	90	15.253	118.173	5.8149	13.8665
BAC	RO	0	0	140.093	0.000	42.0544	0.0000
BAC	RO	0	30	164.227	30.000	49.7430	0.0000
BAC	RO	0	60	173.931	60.000	53.2862	0.0000
BAC	RO	0	90	185.320	90.000	51.4903	0.0000
BAC	RO	5	30	132.867	7.320	34.9611	5.7190
BAC	RO	5	60	143.373	28.893	44.9308	13.7483
BAC	RO	5	90	157.040	51.253	47.9942	19.1015
BAC	RO	25	30	12.972	0.431	7.5879	3.5358
BAC	RO	25	60	73.067	0.080	29.6868	0.6928
BAC	RO	25	90	107.560	7.947	33.5435	9.6084
HIP	R-15	0	30	135.567	30.000	37.7792	0.0000
HIP	R-15	0	60	159.117	60.000	41.8978	0.0000
HIP	R-15	0	90	182.733	90.000	60.1771	0.0000
HIP	R-15	5	30	92.033	11.083	21.1460	2.6636
HIP	R-15	5	60	125.283	28.133	32.0720	8.2183
HIP	R-15	5	90	144.000	49.450	36.9443	12.3157
HIP	R-15	25	30	36.150	2.467	11.3359	3.7165
HIP	R-15	25	60	73.817	13.983	19.7145	4.8759
HIP	R-15	25	90	107.700	28.267	24.2790	18.3440
HIP	R-30	0	30	129.208	30.000	29.6092	0.0000
HIP	R-30	0	60	144.893	60.000	37.2546	0.0000
HIP	R-30	0	90	161.080	90.000	55.0424	0.0000
HIP	R-30	5	30	82.806	10.875	19.2183	3.0208
HIP	R-30	5	60	108.347	28.028	33.0851	7.5358
HIP	R-30	5	90	123.710	51.841	33.3723	12.8700
HIP	R-30	25	30	30.147	2.400	9.5997	3.1751
HIP	R-30	25	60	64.833	15.306	20.5372	8.2268
HIP	R-30	25	90	85.640	27.707	24.1905	12.7701
HIP	RO	0	30	143.153	30.000	37.3584	0.0000
HIP	RO	0	60	179.203	60.000	44.5684	0.0000
HIP	RO	0	90	193.625	90.000	62.1161	0.0000
HIP	RO	5	30	107.306	10.708	23.9351	3.0138
HIP	RO	5	60	139.347	32.139	33.7109	6.1583
HIP	RO	5	90	145.153	53.764	36.1755	11.1286
HIP	RO	25	30	34.747	3.467	14.5789	3.0418
HIP	RO	25	60	81.236	14.375	24.2304	7.9336
HIP	RO	25	90	107.208	20.431	27.2412	11.4065
KNE	R-15	0	30	78.389	30.000	19.2094	0.0000
KNE	R-15	0	60	116.747	60.000	36.1087	0.0000
KNE	R-15	0	90	124.708	90.000	34.8156	0.0000
KNE	R-15	5	30	43.806	13.542	12.2929	2.5869
KNE	R-15	5	60	73.958	36.583	17.8597	5.3068
KNE	R-15	5	90	100.778	57.306	29.8495	7.1378
KNE	R-15	25	30	17.013	0.427	5.6742	1.4628

TABLE 14 CONTINUED. Summary of strength data

JOINT	ROT	SPEED	START	MAXMN	ANGLEMN	MAXSD	ANGLESD
KNE	R-15	25	60	38.840	16.627	12.0259	8.6677
KNE	R-15	25	90	57.560	30.427	16.0558	6.2992
KNE	R-30	0	30	72.200	30.000	14.8096	0.0000
KNE	R-30	0	60	110.587	60.000	29.1608	0.0000
KNE	R-30	0	90	123.389	90.000	32.8578	0.0000
KNE	R-30	5	30	42.107	14.053	11.9634	3.0664
KNE	R-30	5	60	73.907	37.080	21.1060	5.0344
KNE	R-30	5	90	88.542	55.458	29.0802	7.4757
KNE	R-30	25	30	17.493	0.800	10.2461	2.2481
KNE	R-30	25	60	36.280	14.440	10.7698	6.9637
KNE	R-30	25	90	57.449	32.406	13.5598	4.9556
KNE	R0	0	30	65.640	30.000	17.0410	0.0000
KNE	R0	0	60	117.167	60.000	45.6586	0.0000
KNE	R0	0	90	133.413	90.000	41.5624	0.0000
KNE	R0	5	30	39.973	12.960	12.7523	3.3225
KNE	R0	5	60	71.093	36.653	16.9165	5.5422
KNE	R0	5	90	93.236	57.181	19.2950	7.4933
KNE	R0	25	30	16.733	0.547	6.0075	1.5272
KNE	R0	25	60	38.000	13.708	11.3721	5.8417
KNE	R0	25	90	57.236	32.403	17.1591	6.7754
ELB	R-15	0	0	29.907	0.000	8.0306	0.0000
ELB	R-15	0	30	39.653	30.000	10.1387	0.0000
ELB	R-15	0	60	42.613	60.000	9.4981	0.0000
ELB	R-15	0	90	42.292	90.000	10.2359	0.0000
ELB	R-15	5	0	33.760	78.253	8.1933	21.3264
ELB	R-15	5	30	35.736	77.694	8.6773	15.7074
ELB	R-15	5	60	37.627	92.133	7.7682	9.5072
ELB	R-15	5	90	34.278	112.625	8.2158	5.5549
ELB	R-15	25	0	28.145	104.913	6.8712	13.0189
ELB	R-15	25	30	26.667	108.181	6.9647	10.3152
ELB	R-15	25	60	24.405	118.324	5.5982	4.0243
ELB	R-15	25	90	15.813	120.000	3.4039	0.0000
ELB	R-30	0	0	29.440	0.000	6.9927	0.0000
ELB	R-30	0	30	37.227	30.000	7.9127	0.0000
ELB	R-30	0	60	40.240	60.000	7.3371	0.0000
ELB	R-30	0	90	42.347	90.000	8.3996	0.0000
ELB	R-30	5	0	33.467	85.213	6.9230	22.2312
ELB	R-30	5	30	35.667	86.583	7.6674	18.3785
ELB	R-30	5	60	38.613	100.560	6.8278	10.8269
ELB	R-30	5	90	34.960	114.680	5.9852	4.6504
ELB	R-30	25	0	26.027	106.760	5.2761	11.6976
ELB	R-30	25	30	27.427	112.413	5.8982	9.4741
ELB	R-30	25	60	25.587	119.107	5.3904	3.3473
ELB	R-30	25	90	16.267	120.000	3.8776	0.0000
ELB	R0	0	0	28.973	0.000	6.2579	0.0000
ELB	R0	0	30	40.480	30.000	9.2259	0.0000
ELB	R0	0	60	41.493	60.000	8.0327	0.0000
ELB	R0	0	90	39.933	90.000	8.6841	0.0000
ELB	R0	5	0	34.307	59.120	7.0538	18.8256
ELB	R0	5	30	38.027	70.280	8.1952	11.8727
ELB	R0	5	60	33.840	87.840	9.1741	11.7658
ELB	R0	5	90	28.693	110.347	8.4485	4.7661
ELB	R0	25	0	27.347	94.173	6.5005	9.8343
ELB	R0	25	30	25.693	105.213	7.4052	8.8841
ELB	R0	25	60	25.907	115.493	7.5734	6.3382
ELB	R0	25	90	13.920	120.000	4.0927	0.0000

TABLE 14 CONTINUED. Summary of strength data

JOINT	ROT	SPEED	START	MAXMN	ANGLEMN	MAXSD	ANGLESD
ELB	R15	0	0	30.8472	0.000	6.1568	0.0000
ELB	R15	0	30	43.8667	30.000	8.2205	0.0000
ELB	R15	0	60	45.1667	60.000	9.2569	0.0000
ELB	R15	0	90	43.5733	90.000	9.0213	0.0000
ELB	R15	5	0	36.4000	58.693	6.8497	15.1304
ELB	R15	5	30	39.0933	71.240	7.2245	15.7247
ELB	R15	5	60	37.0800	87.653	7.2200	6.8230
ELB	R15	5	90	27.9333	110.920	6.2996	4.8651
ELB	R15	25	0	27.0267	91.320	5.2013	12.0451
ELB	R15	25	30	27.0800	100.587	5.4569	9.9459
ELB	R15	25	60	23.2667	112.933	4.8889	6.8878
ELB	R15	25	90	14.3867	120.000	4.5764	0.0000
ELB	R30	0	0	29.1111	0.000	6.1976	0.0000
ELB	R30	0	30	41.6667	30.000	9.0460	0.0000
ELB	R30	0	60	45.5694	60.000	9.1603	0.0000
ELB	R30	0	90	43.6389	90.000	9.7263	0.0000
ELB	R30	5	0	35.9306	63.611	6.3674	13.0552
ELB	R30	5	30	38.9696	67.087	8.2067	10.5757
ELB	R30	5	60	36.8133	86.587	8.3256	5.6403
ELB	R30	5	90	27.4133	110.907	6.1449	4.8356
ELB	R30	25	0	26.2933	92.373	5.3037	11.9127
ELB	R30	25	30	25.8194	98.833	6.0592	8.4570
ELB	R30	25	60	22.7536	115.565	4.2717	6.4226
ELB	R30	25	90	13.1884	119.884	3.4097	0.9631
HFE	R0	0	0	34.7600	0.000	10.6490	0.0000
HFE	R0	0	30	45.6533	31.200	18.1231	10.3923
HFE	R0	0	60	46.6933	60.000	14.0395	0.0000
HFE	R0	0	90	50.2800	90.000	15.7442	0.0000
HFE	R0	5	0	37.9855	79.609	12.2924	30.3219
HFE	R0	5	30	40.6667	85.453	13.4449	19.6650
HFE	R0	5	60	42.9167	95.653	14.5996	11.8466
HFE	R0	5	90	43.6533	114.933	13.2924	5.6839
HFE	R0	25	0	30.6933	99.960	9.7120	15.7115
HFE	R0	25	30	32.5867	104.640	10.7529	12.8994
HFE	R0	25	60	34.0133	115.973	10.2845	5.6184
HFE	R0	25	90	24.3467	120.093	9.8632	1.0676
VFE	R-15	0	0	40.0133	0.000	12.1282	0.0000
VFE	R-15	0	30	36.9306	30.000	8.8307	0.0000
VFE	R-15	0	60	40.3333	60.000	7.3429	0.0000
VFE	R-15	0	90	44.9091	90.000	7.9377	0.0000
VFE	R-15	5	0	35.6133	81.533	8.7269	36.3442
VFE	R-15	5	30	34.4493	106.913	5.4733	14.6817
VFE	R-15	5	60	35.4507	105.211	7.0362	12.5936
VFE	R-15	5	90	37.0000	117.542	8.2530	3.8086
VFE	R-15	25	0	29.2576	114.318	5.5117	11.6542
VFE	R-15	25	30	28.7424	118.455	5.8159	4.7172
VFE	R-15	25	60	29.6667	118.500	5.1403	4.2559
VFE	R-15	25	90	20.4533	120.000	7.6340	0.0000
VFE	R-30	0	0	41.1200	0.000	10.5433	0.0000
VFE	R-30	0	30	39.3194	30.000	9.0052	0.0000
VFE	R-30	0	60	43.3867	60.000	8.4180	0.0000
VFE	R-30	0	90	46.4667	90.000	9.6062	0.0000
VFE	R-30	5	0	35.1333	90.573	6.8858	34.3716
VFE	R-30	5	30	36.8000	94.187	7.2727	19.4469
VFE	R-30	5	60	36.5833	104.361	6.1707	13.8587
VFE	R-30	5	90	37.0667	116.160	7.1666	5.6258

TABLE 14 CONTINUED. Summary of strength data

JOINT	ROT	SPEED	START	MAXMN	ANGLEMN	MAXSD	ANGLESD
VFE	R-30	25	0	28.5733	115.707	6.2928	8.1070
VFE	R-30	25	30	30.7467	118.093	6.5246	5.2689
VFE	R-30	25	60	29.2917	119.875	6.8965	0.7861
VFE	R-30	25	90	20.6000	120.000	5.9977	0.0000
VFE	R0	0	0	40.8400	0.000	11.2527	0.0000
VFE	R0	0	30	36.9067	30.000	8.3394	0.0000
VFE	R0	0	60	40.0800	60.000	5.4171	0.0000
VFE	R0	0	90	46.7733	90.000	8.0397	0.0000
VFE	R0	5	0	38.6667	86.667	6.8819	39.2464
VFE	R0	5	30	38.4400	103.000	7.1834	23.6197
VFE	R0	5	60	40.3867	110.080	6.8830	10.8960
VFE	R0	5	90	40.5600	118.400	6.5847	2.9409
VFE	R0	25	0	29.5067	110.427	5.7666	18.6281
VFE	R0	25	30	29.0800	116.760	6.1022	8.6381
VFE	R0	25	60	29.9067	119.400	5.6333	2.1053
VFE	R0	25	90	19.7867	120.000	5.7051	0.0000
VFE	R15	0	0	38.8000	0.000	13.9361	0.0000
VFE	R15	0	30	41.3333	30.000	13.3448	0.0000
VFE	R15	0	60	39.2667	60.000	9.8849	0.0000
VFE	R15	0	90	45.6667	90.000	7.0334	0.0000
VFE	R15	5	0	35.7467	74.720	7.9765	41.8794
VFE	R15	5	30	37.0667	105.627	7.0793	21.4418
VFE	R15	5	60	40.2083	111.778	5.8837	9.3194
VFE	R15	5	90	38.3600	118.547	7.6717	3.2353
VFE	R15	25	0	28.1733	106.427	5.8503	22.8238
VFE	R15	25	30	28.3333	116.181	6.6099	9.5524
VFE	R15	25	60	26.9067	120.333	6.1097	4.3101
VFE	R15	25	90	19.8533	120.787	6.2896	2.7622
VFE	R30	0	0	42.4722	0.000	16.3801	0.0000
VFE	R30	0	30	40.8800	30.000	10.2627	0.0000
VFE	R30	0	60	36.7333	60.000	7.8056	0.0000
VFE	R30	0	90	43.2400	90.000	7.8857	0.0000
VFE	R30	5	0	36.0000	73.040	6.2952	42.2670
VFE	R30	5	30	34.5867	92.187	6.3695	28.3309
VFE	R30	5	60	36.8600	107.800	7.1091	12.5967
VFE	R30	5	90	36.6933	117.467	5.9977	4.7770
VFE	R30	25	0	28.5467	99.280	7.0793	25.8015
VFE	R30	25	30	28.0800	114.907	6.4510	15.1445
VFE	R30	25	60	26.3067	119.880	5.5409	1.0392
VFE	R30	25	90	18.3867	120.000	4.6321	0.0000

TABLE 14 CONTINUED. Summary of strength data

JOINT	ROT	SPEED	START	MAXMIN	MAXMAX	MAXSKEW	MAXKURT
ABD	RO	0	0	17	73	-0.32371	-0.2772
ABD	RO	0	30	11	53	-0.57925	0.4731
ABD	RO	0	60	14	54	-0.24616	-0.3362
ABD	RO	0	90	15	53	0.17399	-0.2542
ABD	RO	5	0	21	46	0.15978	-0.7321
ABD	RO	5	30	11	43	-0.16978	-0.3114
ABD	RO	5	60	17	46	0.22421	-0.2840
ABD	RO	5	90	13	47	0.27199	-0.3939
ABD	RO	25	0	12	37	0.02755	-0.0918
ABD	RO	25	30	10	33	-0.43861	0.2853
ABD	RO	25	60	6	38	-0.23546	-0.1880
ABD	RO	25	90	0	28	-0.10760	0.0284
BAC	RO	0	0	70	231	0.02130	-0.8562
BAC	RO	0	30	36	288	0.00115	0.6246
BAC	RO	0	60	45	270	-0.50453	0.3063
BAC	RO	0	90	66	292	-0.26802	0.1058
BAC	RO	5	30	63	206	0.20840	-0.7272
BAC	RO	5	60	34	236	-0.16023	-0.3178
BAC	RO	5	90	54	290	0.46391	0.5256
BAC	RO	25	30	0	32	0.67554	0.3671
BAC	RO	25	60	7	137	-0.25571	-0.5713
BAC	RO	25	90	20	180	-0.42907	0.1353
HIP	R-15	0	30	70	192	-0.17559	-1.3610
HIP	R-15	0	60	90	244	0.07579	-1.2902
HIP	R-15	0	90	73	294	0.09374	-0.9237
HIP	R-15	5	30	57	133	0.23432	-1.0012
HIP	R-15	5	60	68	189	0.04467	-0.7852
HIP	R-15	5	90	62	209	-0.42630	-0.6312
HIP	R-15	25	30	12	60	-0.13513	-0.2840
HIP	R-15	25	60	32	104	-0.54274	-0.6164
HIP	R-15	25	90	48	145	-0.95685	-0.0250
HIP	R-30	0	30	72	200	0.00369	-0.6269
HIP	R-30	0	60	84	260	0.79241	0.6687
HIP	R-30	0	90	56	320	0.46058	0.3704
HIP	R-30	5	30	47	134	0.58141	0.2223
HIP	R-30	5	60	11	190	-0.43165	1.4371
HIP	R-30	5	90	60	192	0.04911	-0.7234
HIP	R-30	25	30	12	50	-0.29844	-0.8151
HIP	R-30	25	60	21	108	-0.25737	-0.2792
HIP	R-30	25	90	45	170	0.90529	1.8723
HIP	RO	0	30	70	208	-0.18324	-0.9636
HIP	RO	0	60	93	276	-0.21732	-0.7960
HIP	RO	0	90	49	300	-0.54858	-0.4959
HIP	RO	5	30	48	157	-0.29102	-0.3972
HIP	RO	5	60	64	196	-0.26312	-0.7913
HIP	RO	5	90	74	221	-0.23474	-0.9080
HIP	RO	25	30	3	75	0.40407	0.2679
HIP	RO	25	60	27	132	-0.17386	-0.4977
HIP	RO	25	90	55	157	-0.26927	-1.0387
KNE	R-15	0	30	44	124	0.38753	-0.6477
KNE	R-15	0	60	50	216	0.66973	0.7756
KNE	R-15	0	90	54	222	0.43778	0.1832
KNE	R-15	5	30	24	78	0.55956	0.1141
KNE	R-15	5	60	38	110	0.19528	-0.6080
KNE	R-15	5	90	42	174	0.56127	-0.1203
KNE	R-15	25	30	6	30	0.17198	-0.4310

TABLE 14 CONTINUED. Summary of strength data

JOINT	ROT	SPEED	START	MAXMIN	MAXMAX	MAXSKEW	MAXKURT
KNE	R-15	25	60	19	66	0.4668	-0.8248
KNE	R-15	25	90	22	90	-0.2780	-0.4909
KNE	R-30	0	30	40	100	-0.3569	-0.5028
KNE	R-30	0	60	60	168	-0.1351	-1.0972
KNE	R-30	0	90	56	212	0.5342	0.6560
KNE	R-30	5	30	17	66	0.1525	-0.8101
KNE	R-30	5	60	24	132	-0.0992	0.5982
KNE	R-30	5	90	41	171	0.7622	0.8179
KNE	R-30	25	30	8	62	2.9792	10.2513
KNE	R-30	25	60	14	65	0.2486	0.0024
KNE	R-30	25	90	32	84	0.1875	-0.6426
KNE	R0	0	30	38	100	0.3325	-1.0817
KNE	R0	0	60	60	277	1.6336	3.2119
KNE	R0	0	90	67	258	0.8578	0.5569
KNE	R0	5	30	16	68	0.1248	-0.4287
KNE	R0	5	60	30	110	0.1954	-0.3835
KNE	R0	5	90	54	143	0.1320	-0.1292
KNE	R0	25	30	5	28	0.1299	-0.8709
KNE	R0	25	60	14	57	-0.2455	-0.9063
KNE	R0	25	90	21	108	0.2626	0.5118
ELB	R-15	0	0	11	48	0.3242	0.0940
ELB	R-15	0	30	13	64	-0.4762	0.6790
ELB	R-15	0	60	14	66	-0.3485	1.5870
ELB	R-15	0	90	15	64	-0.5863	0.6693
ELB	R-15	5	0	16	51	0.0579	-0.1479
ELB	R-15	5	30	18	55	0.0973	-0.4167
ELB	R-15	5	60	18	57	0.1296	0.7955
ELB	R-15	5	90	21	51	0.2646	-0.6409
ELB	R-15	25	0	18	43	0.4703	-0.7347
ELB	R-15	25	30	13	44	0.2883	-0.5049
ELB	R-15	25	60	13	41	0.4528	0.2405
ELB	R-15	25	90	8	22	-0.5032	-0.2805
ELB	R-30	0	0	17	46	0.2766	-0.6897
ELB	R-30	0	30	12	52	-0.8975	1.6315
ELB	R-30	0	60	15	52	-1.1533	2.6211
ELB	R-30	0	90	17	55	-1.2066	1.5889
ELB	R-30	5	0	16	45	-0.7263	0.2205
ELB	R-30	5	30	13	55	-0.0945	1.1119
ELB	R-30	5	60	20	52	-0.5433	0.5145
ELB	R-30	5	90	22	48	0.0072	-0.5091
ELB	R-30	25	0	15	39	0.1015	-0.2199
ELB	R-30	25	30	15	41	0.0321	0.0273
ELB	R-30	25	60	10	36	-0.5446	0.3513
ELB	R-30	25	90	6	26	-0.4733	0.9662
ELB	R0	0	0	18	48	0.2289	0.2927
ELB	R0	0	30	19	61	-0.2479	-0.6218
ELB	R0	0	60	24	55	-0.3613	-0.7085
ELB	R0	0	90	22	64	0.1216	-0.1597
ELB	R0	5	0	20	46	-0.5455	-0.7431
ELB	R0	5	30	22	60	0.5688	0.1299
ELB	R0	5	60	18	59	0.2840	0.0426
ELB	R0	5	90	12	54	0.4592	0.2095
ELB	R0	25	0	18	42	0.7153	-0.5942
ELB	R0	25	30	12	42	0.2178	-0.4795
ELB	R0	25	60	12	41	0.1455	-0.7030
ELB	R0	25	90	7	26	0.6569	0.3844

TABLE 14 CONTINUED. Summary of strength data

JOINT	ROT	SPEED	START	MAXMIN	MAXMAX	MAXSKEW	MAXKURT
ELB	R15	0	0	13	43	-0.3926	0.3364
ELB	R15	0	30	13	56	-1.9801	4.5763
ELB	R15	0	60	24	69	0.1697	0.6274
ELB	R15	0	90	24	63	0.1794	-0.7233
ELB	R15	5	0	21	54	0.1871	0.4047
ELB	R15	5	30	24	55	0.1829	-0.5786
ELB	R15	5	60	26	54	0.2719	-0.6988
ELB	R15	5	90	15	43	0.3582	-0.0177
ELB	R15	25	0	14	37	-0.2317	-0.0792
ELB	R15	25	30	18	38	0.2788	-0.7411
ELB	R15	25	60	14	34	0.3467	-0.6854
ELB	R15	25	90	2	22	-0.4376	-0.1435
ELB	R30	0	0	13	45	0.1372	0.7860
ELB	R30	0	30	16	64	-0.2471	0.6683
ELB	R30	0	60	21	69	0.1693	0.9424
ELB	R30	0	90	24	62	0.0693	-0.8571
ELB	R30	5	0	20	49	0.0310	-0.1047
ELB	R30	5	30	19	54	-0.3132	-0.1009
ELB	R30	5	60	18	58	0.1190	-0.0020
ELB	R30	5	90	16	42	0.2340	-0.6536
ELB	R30	25	0	18	42	0.5109	-0.0694
ELB	R30	25	30	10	39	0.0642	0.1099
ELB	R30	25	60	12	31	-0.2026	-0.3777
ELB	R30	25	90	4	20	0.1046	0.2441
HFE	R0	0	0	11	52	-0.4264	-0.7087
HFE	R0	0	30	21	125	2.0641	6.4604
HFE	R0	0	60	19	68	-0.1650	-0.9377
HFE	R0	0	90	22	75	-0.2038	-1.2752
HFE	R0	5	0	16	65	0.1679	-0.4566
HFE	R0	5	30	16	66	0.1702	-0.7947
HFE	R0	5	60	16	68	0.0733	-1.2314
HFE	R0	5	90	14	72	-0.1525	-0.5370
HFE	R0	25	0	11	47	-0.4077	-0.9139
HFE	R0	25	30	12	53	-0.3692	-0.7608
HFE	R0	25	60	10	57	-0.4036	-0.1339
HFE	R0	25	90	5	42	-0.0144	-0.9996
VFE	R-15	0	0	15	66	-0.0730	-0.4149
VFE	R-15	0	30	14	58	0.1378	0.3676
VFE	R-15	0	60	24	55	-0.0654	-0.7429
VFE	R-15	0	90	22	60	-1.0481	1.3421
VFE	R-15	5	0	9	53	-1.0515	1.7560
VFE	R-15	5	30	25	48	0.5456	-0.4251
VFE	R-15	5	60	15	50	-0.5142	0.8575
VFE	R-15	5	90	9	56	-0.8681	3.4173
VFE	R-15	25	0	20	43	0.4414	-0.3434
VFE	R-15	25	30	19	44	0.2306	-0.4328
VFE	R-15	25	60	16	39	-0.4742	-0.1176
VFE	R-15	25	90	5	31	-0.4097	-0.9349
VFE	R-30	0	0	14	63	-0.0182	0.1806
VFE	R-30	0	30	13	57	-0.8281	1.2273
VFE	R-30	0	60	22	63	0.2052	0.8739
VFE	R-30	0	90	18	64	-0.7743	1.0809
VFE	R-30	5	0	20	54	0.1734	0.2239
VFE	R-30	5	30	21	51	-0.0245	-0.5304
VFE	R-30	5	60	21	47	-0.3699	0.0561
VFE	R-30	5	90	20	55	-0.2365	0.2536

TABLE 14 CONTINUED. Summary of strength data

JOINT	ROT	SPEED	START	MAXMIN	MAXMAX	MAXSKEW	MAXKURT
VFE	R-30	25	0	16	44	0.08718	-0.7528
VFE	R-30	25	30	17	46	0.08969	-0.0708
VFE	R-30	25	60	16	48	0.45599	-0.0450
VFE	R-30	25	90	5	33	-0.47405	-0.1394
VFE	R0	0	0	19	68	0.33001	-0.0959
VFE	R0	0	30	17	54	-0.41352	-0.5178
VFE	R0	0	60	30	51	-0.01094	-0.7455
VFE	R0	0	90	32	66	0.29438	0.1144
VFE	R0	5	0	26	52	-0.04513	-1.0580
VFE	R0	5	30	22	58	0.05806	-0.2109
VFE	R0	5	60	26	56	-0.09801	-0.4120
VFE	R0	5	90	26	52	-0.34242	-0.8696
VFE	R0	25	0	18	40	0.15653	-1.2136
VFE	R0	25	30	19	44	0.28697	-0.8414
VFE	R0	25	60	17	39	-0.62291	-0.4225
VFE	R0	25	90	4	30	-0.40851	0.5448
VFE	R15	0	0	8	72	0.08857	-0.1500
VFE	R15	0	30	12	69	0.23146	-0.2091
VFE	R15	0	60	11	66	-0.14808	1.9073
VFE	R15	0	90	28	60	-0.21395	-0.2984
VFE	R15	5	0	20	56	0.27205	-0.4250
VFE	R15	5	30	18	50	-0.37468	-0.0118
VFE	R15	5	60	26	50	-0.21920	-0.8846
VFE	R15	5	90	18	53	-0.60164	0.2918
VFE	R15	25	0	17	41	0.22698	-0.7901
VFE	R15	25	30	16	42	0.24758	-0.6844
VFE	R15	25	60	13	38	-0.29594	-0.3855
VFE	R15	25	90	2	37	0.01034	1.4182
VFE	R30	0	0	14	93	0.91045	1.4628
VFE	R30	0	30	10	59	-0.80858	0.6111
VFE	R30	0	60	19	51	-0.42843	-0.5861
VFE	R30	0	90	21	58	-0.77351	0.6619
VFE	R30	5	0	17	62	0.68869	1.9828
VFE	R30	5	30	21	49	0.12449	-0.5132
VFE	R30	5	60	20	49	-0.12383	-0.5381
VFE	R30	5	90	24	50	-0.17271	-0.4370
VFE	R30	25	0	18	45	0.41585	-0.7773
VFE	R30	25	30	10	40	-0.41741	0.2122
VFE	R30	25	60	13	37	-0.25213	-0.3989
VFE	R30	25	90	3	27	-0.83803	1.3783

Another problem encountered involved the warm-up calibration procedure. The pen of the torque channel would drift away from the baseline position and no adjustments of the controls would cause it to return to normal operating positions. After consulting with the manufacturer again, the cause of the problem was determined and corrected. However, some data were lost because of this problem.

For some of the variable combinations, the zero reference point for the range of motion was not maintained by the subject. This rendered some of the data unuseable.

A third difficulty was the rescheduling of subjects once the error in data collection was discovered. Many time the end of the semester had come making subjects unavailable or they had graduated again resulting in their being unavailable.

The Strength Data

A summary of the strength data is presented in Table 14. The data are listed according to joint first (column 1). The other variables are the angle of rotation (ROT), speed of motion (SPEED) and lastly the starting angle of the motion (START) in columns 2 through 4 respectively. Each line of the table is uniquely defined by a combination of joint, rotation angle, speed, and starting angle.

The data contained on each line consist of the mean in foot pounds, standard deviation in foot pounds, coefficient of variation as a percent, and measures of skewness and kurtsois

for the maximum torque (column 5, 7, 9-11). Columns 6 and 8 contain the mean angle at which the maximum torque occurred and its standard deviation.

Data Retrieval

The information desired must be identified according to the identification format used in the table. As an example, say the torque of the elbow in the sagittal plane starting from an angle of 30 degrees above a fully extended arm is desired for a speed of five RPM. The selection must be identified as ELB, R0, 25, 30 or in other words elbow, rotation of 0, speed of 25 RPM, and starting angle of 30 degrees.

Using this defintion, the user would enter the table first at column 1 with the joint: elbow. Having found ELB in column one, move to R0 in column two followed by 25 in column 3. Finally moving to 30 in column 4 would identify the data line desired. The data for this combination of variables is as follows:

MAXMN (mean maximum torque) = 26.402 ft-lb

ANGLEMN (mean angle of max. T.) = 104.606°

MAXSD (standard dev. of the max. T.) = 6.5613 ft-lb

ANGLESD (standard dev. of the max. T.) = 9.2264°

MAXCV (coefficient of variation of max. T.) = 24.8522%

MAXSKEW (skewness measure of max. T.) = .1136

MAXKURT (kurtosis measure of max. T.) = -.23045

Effect of the Variables on Maximum Torque

Each of the independent variables are discussed separately. The data contained in Table 14 is the source for all discussion in this section. Plot of the maximum torque as a function of speed with the four starting angles as treatment conditions for all joint rotation combinations are presented in Figures 36-54. Note that differences smaller than 1.5 ft-lb for torques less than 180 ft-lbs and 3 ft-lb. for torques larger than 180 ft-lbs should be interpreted with caution since the smallest division of the two most often used scales, namely 180 ft-lb and 360 ft-lb, were 6 ft-lb and 12 ft-lb respectively (see the figures 34 and 35 in the procedure section showing the sample data record and scaling card).

Speed Variable

In general the maximum torque appears to decrease as the speed increases. Three exceptions are observed. The first is for the elbow joint. (Figures 38-42). For all cases, the static measure at the zero degree start is relatively low. The reason for this low value could be due to the full extension of the arm required for this starting position which places the elbow joint at a very poor mechanical advantage. This could account for the low torques observed for the static zero start combination. The second reason is the low torque observed for the static zero start combination (Figure 43) for the horizontal felxion at the shoulder (HFE). Again the muscle is in a stretched condition and the mechanical advantage is relatively low.

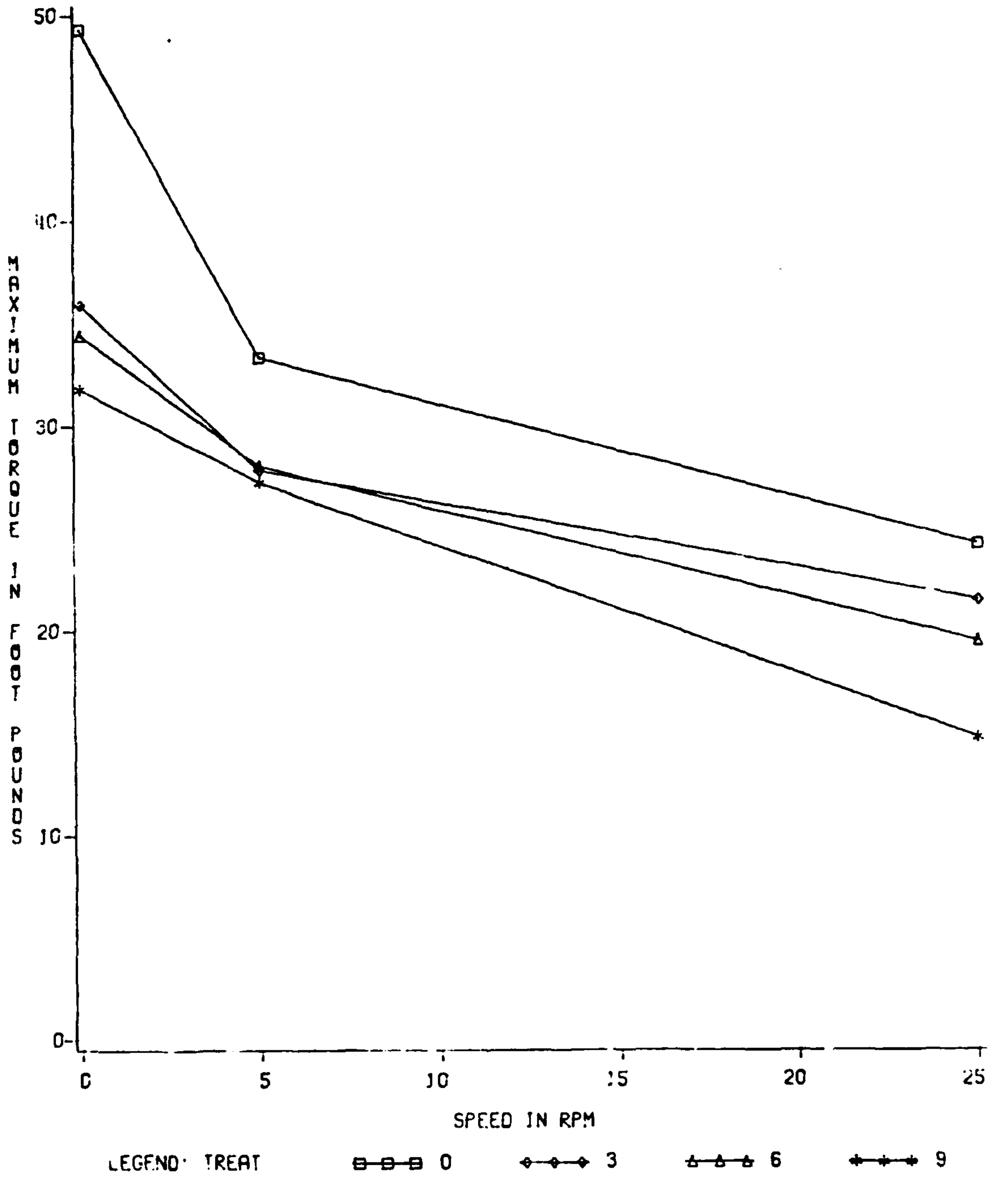

FIGURE 36 MAXIMUM TORQUE VS SPEED FOR ABD AND ROTATION OF 0 DEGREES

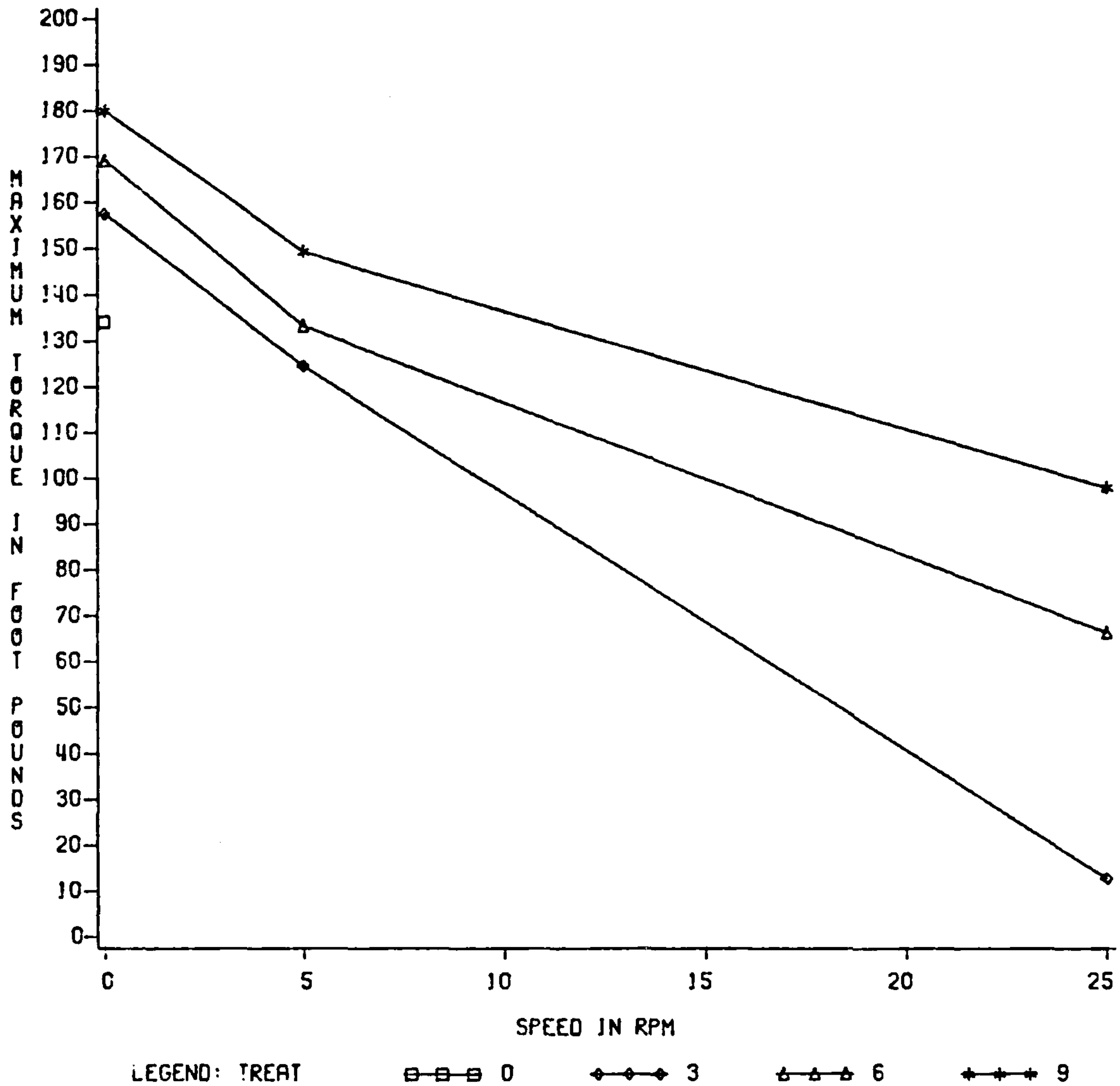

FIGURE 37 MAXIMUM TORQUE VS SPEED FOR BAC AND ROTATION OF 0 DEGREES

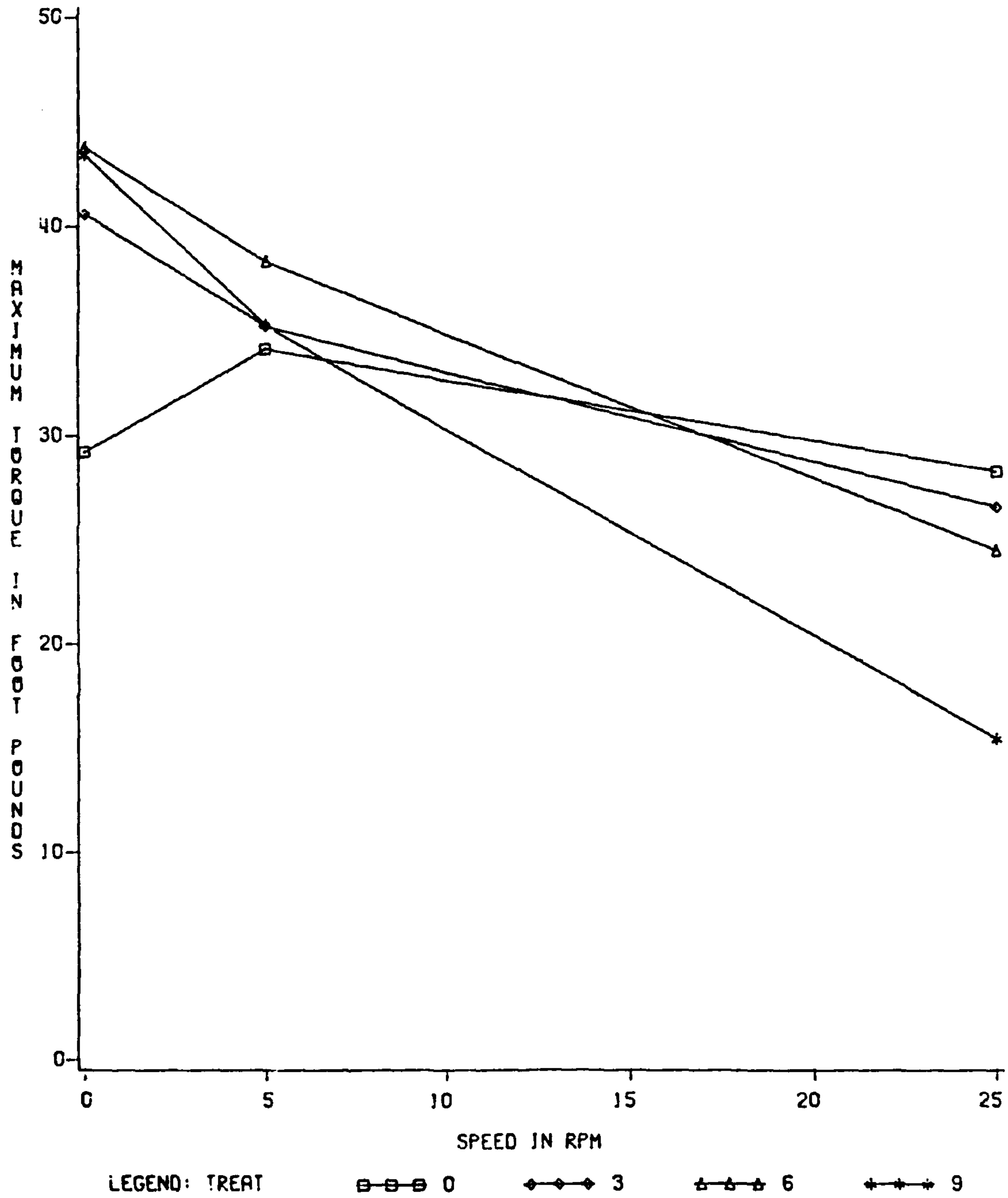

FIGURE 38 MAXIMUM TORQUE VS SPEED FOR ELB AND ROTATION OF −15 DEGREES

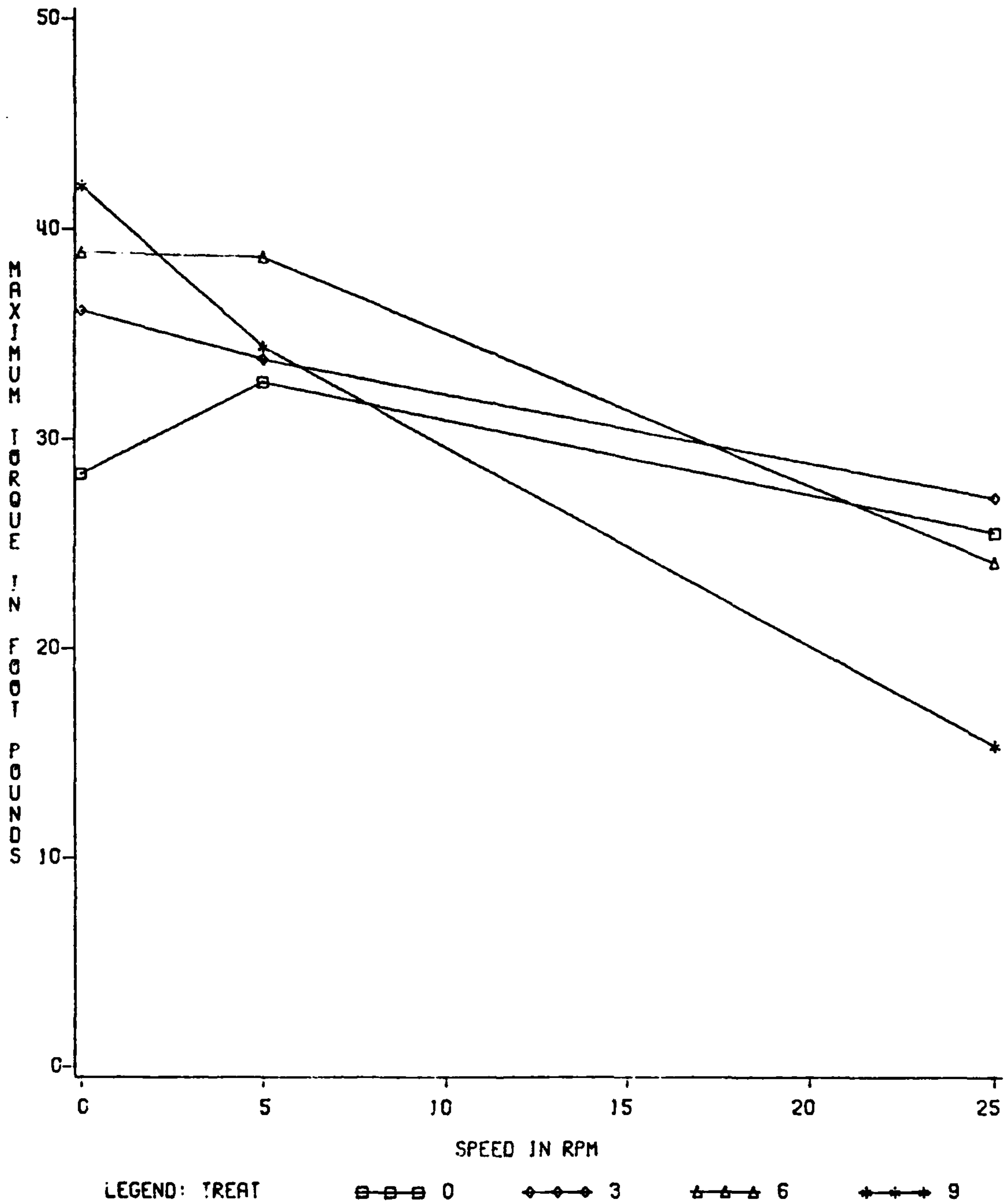

FIGURE 39 MAXIMUM TORQUE VS SPEED FOR ELB AND ROTATION OF −30 DEGREES

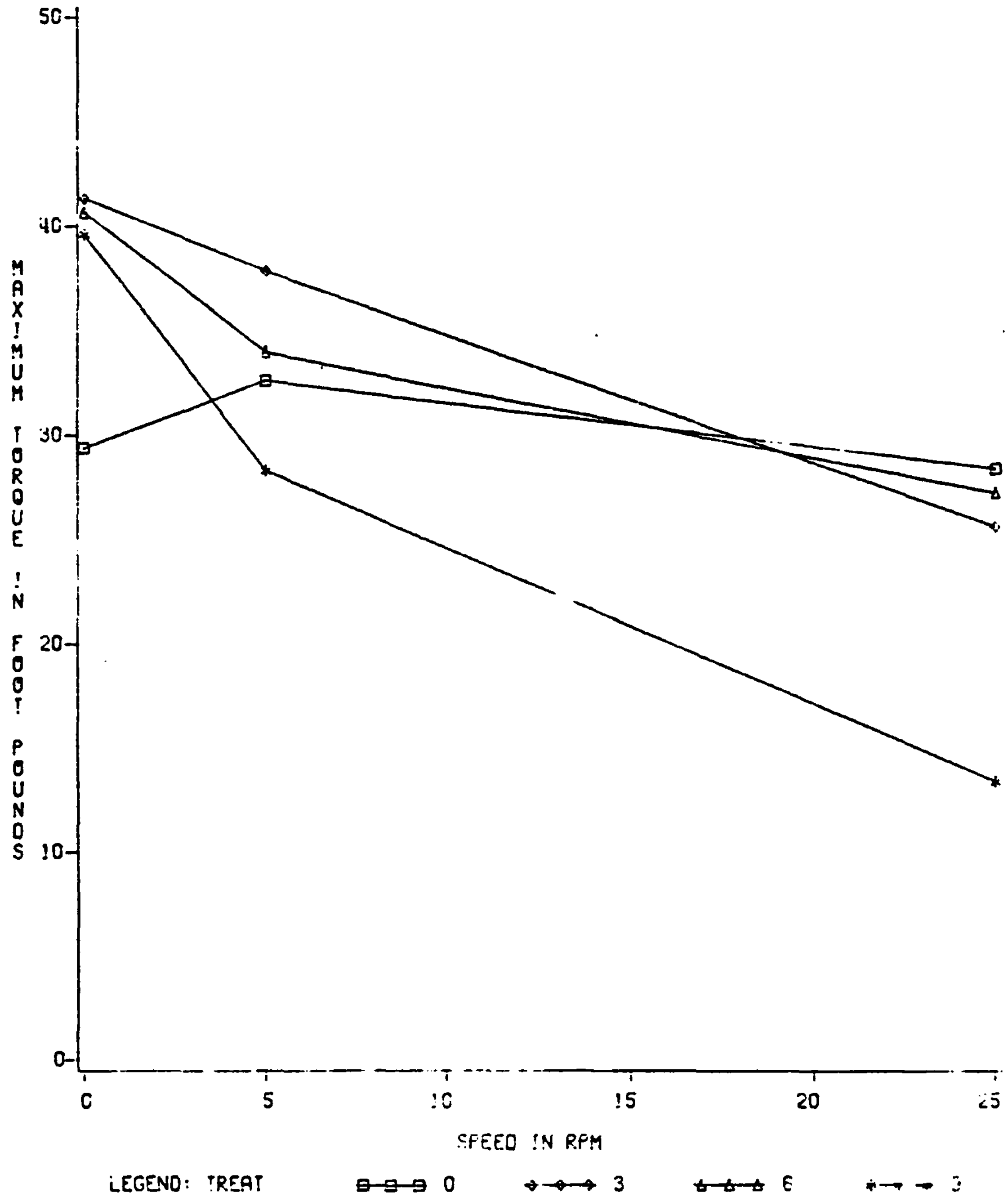

FIGURE 40 MAXIMUM TORQUE VS SPEED FOR ELB AND ROTATION OF 0 DEGREES

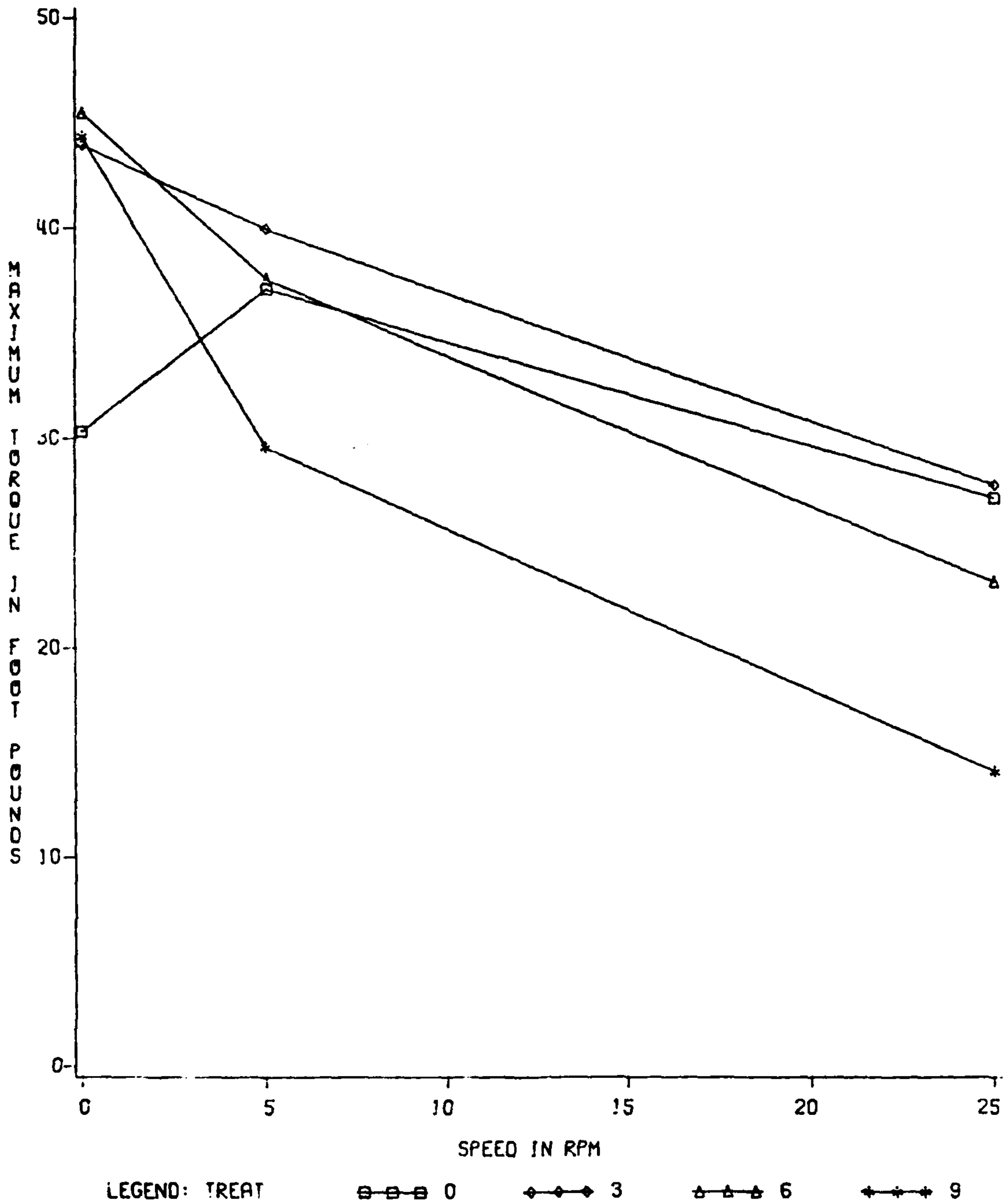

FIGURE 41 MAXIMUM TORQUE VS SPEED FOR ELB AND ROTATION OF 15 DEGREES

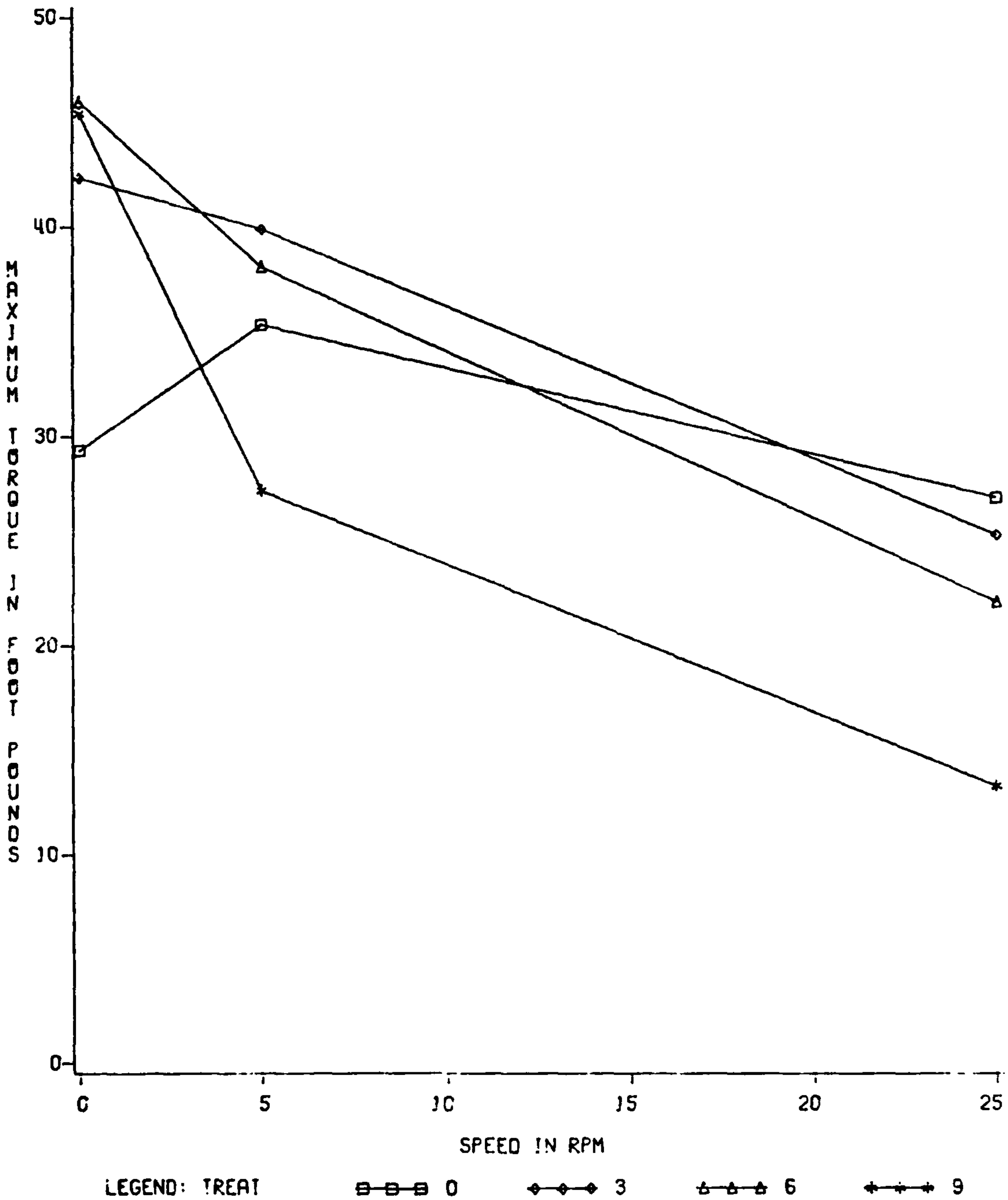

FIGURE 42 MAXIMUM TORQUE VS SPEED FOR ELB AND ROTATION OF 30 DEGREES

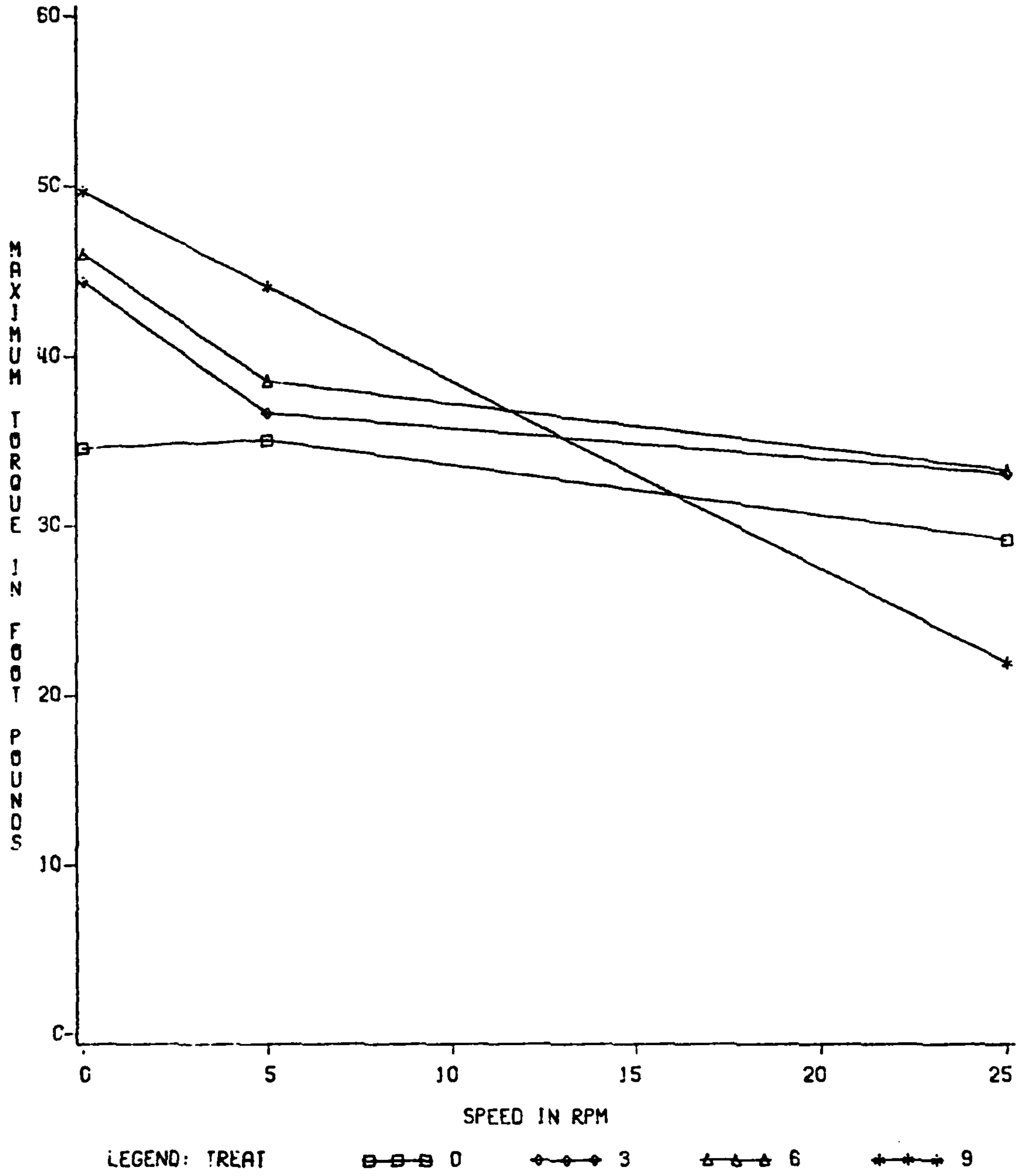

FIGURE 43 MAXIMUM TORQUE VS SPEED FOR HFE AND ROTATION OF 0 DEGREES

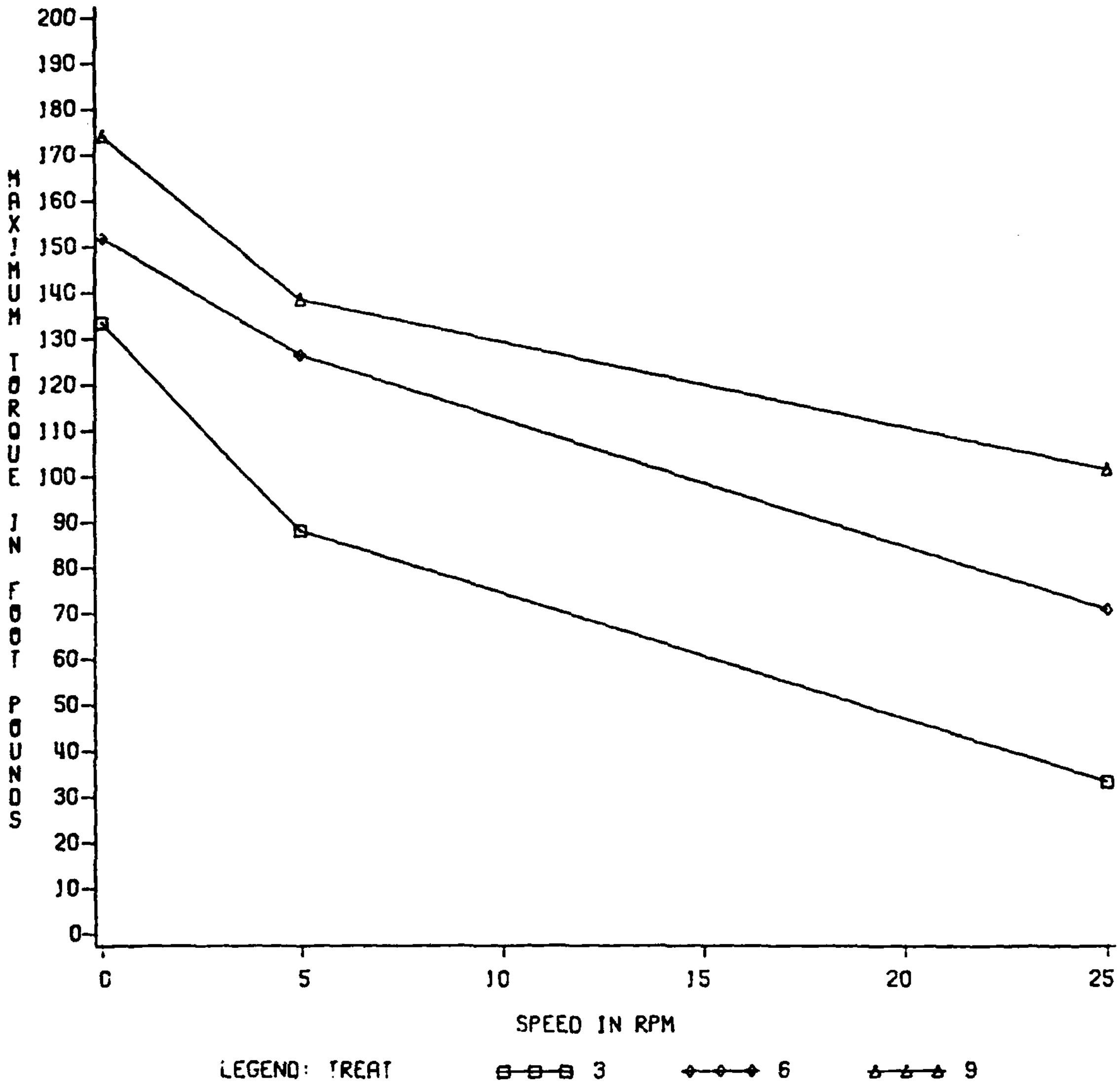

FIGURE 44 MAXIMUM TORQUE VS SPEED FOR HIP AND ROTATION OF −15 DEGREES

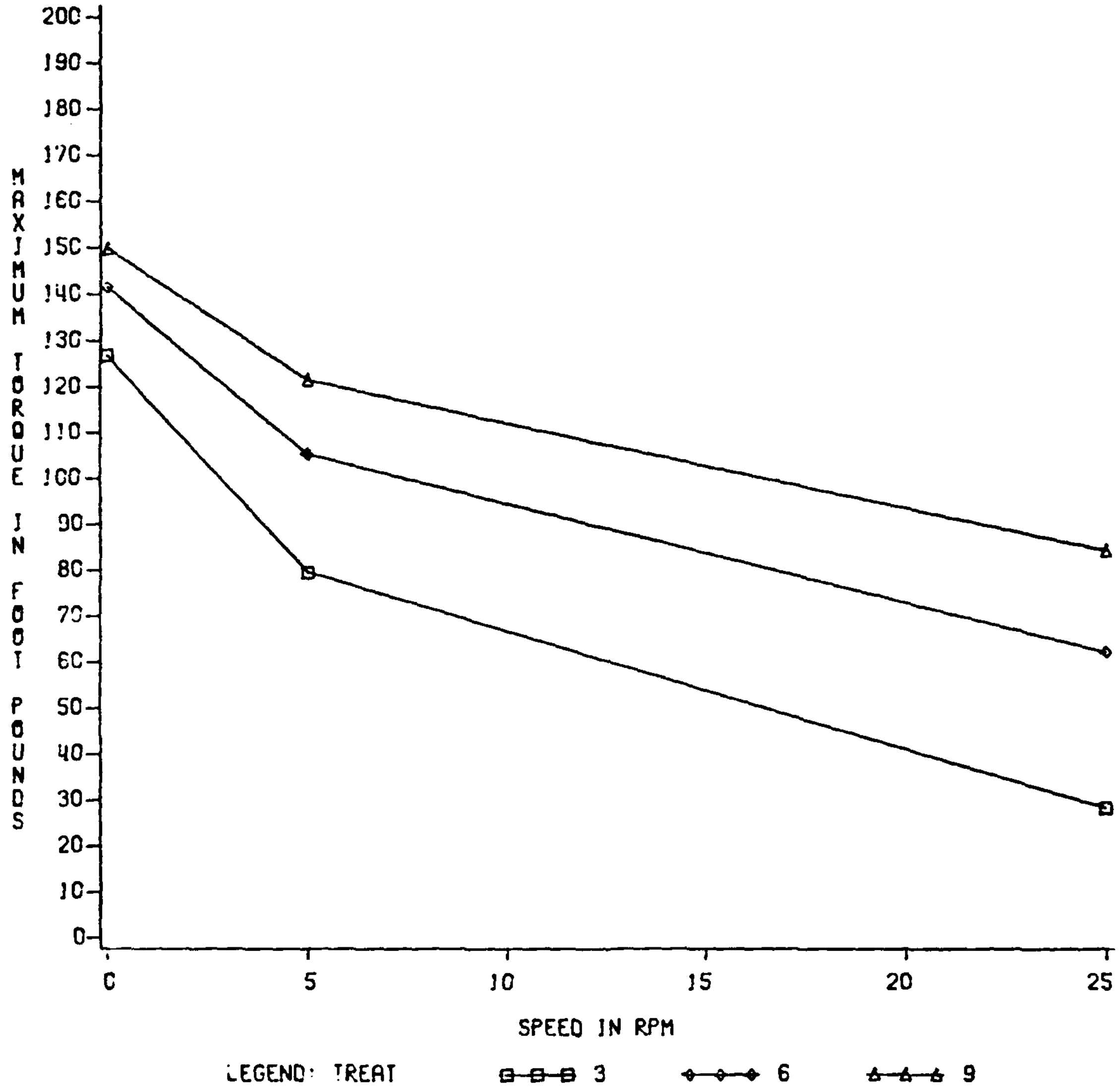

FIGURE 45 MAXIMUM TORQUE VS SPEED FOR HIP AND ROTATION OF −30 DEGREES

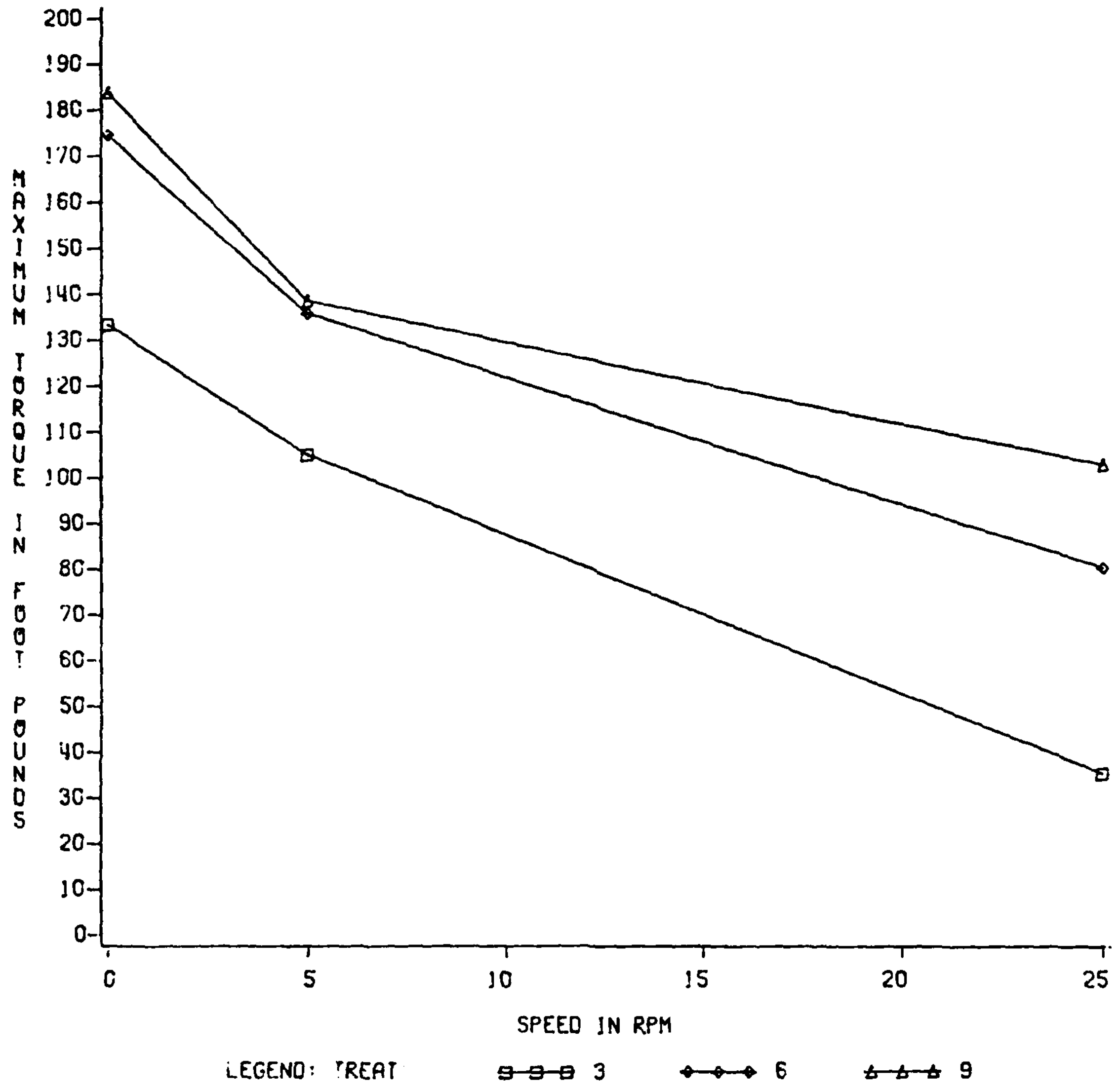

FIGURE 46 MAXIMUM TORQUE VS SPEED FOR HIP AND ROTATION OF 0 DEGREES

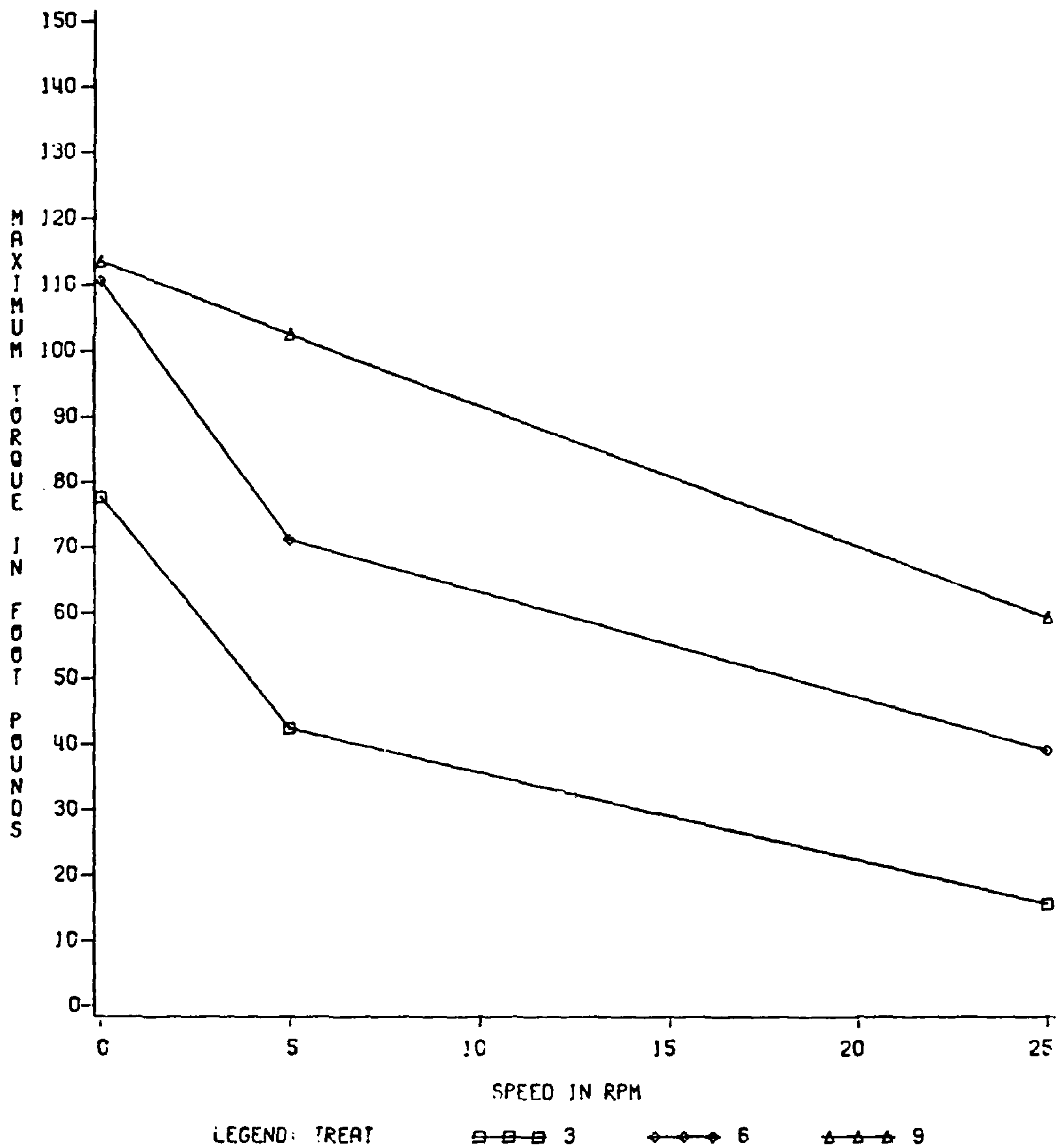

FIGURE 47 MAXIMUM TORQUE VS SPEED FOR KNE AND ROTATION OF −15 DEGREES

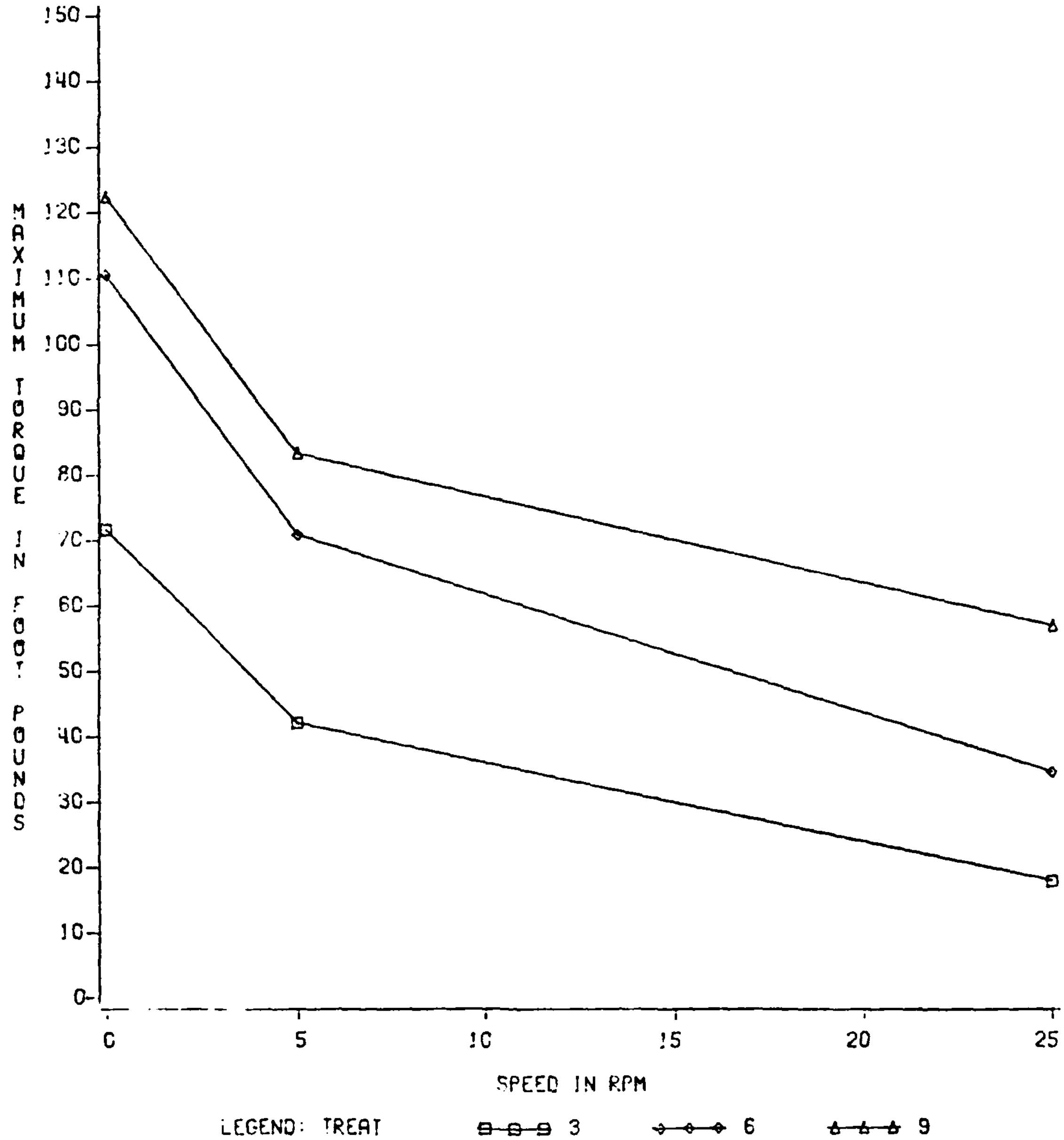

FIGURE 48 MAXIMUM TORQUE VS SPEED FOR KNE AND ROTATION OF −30 DEGREES

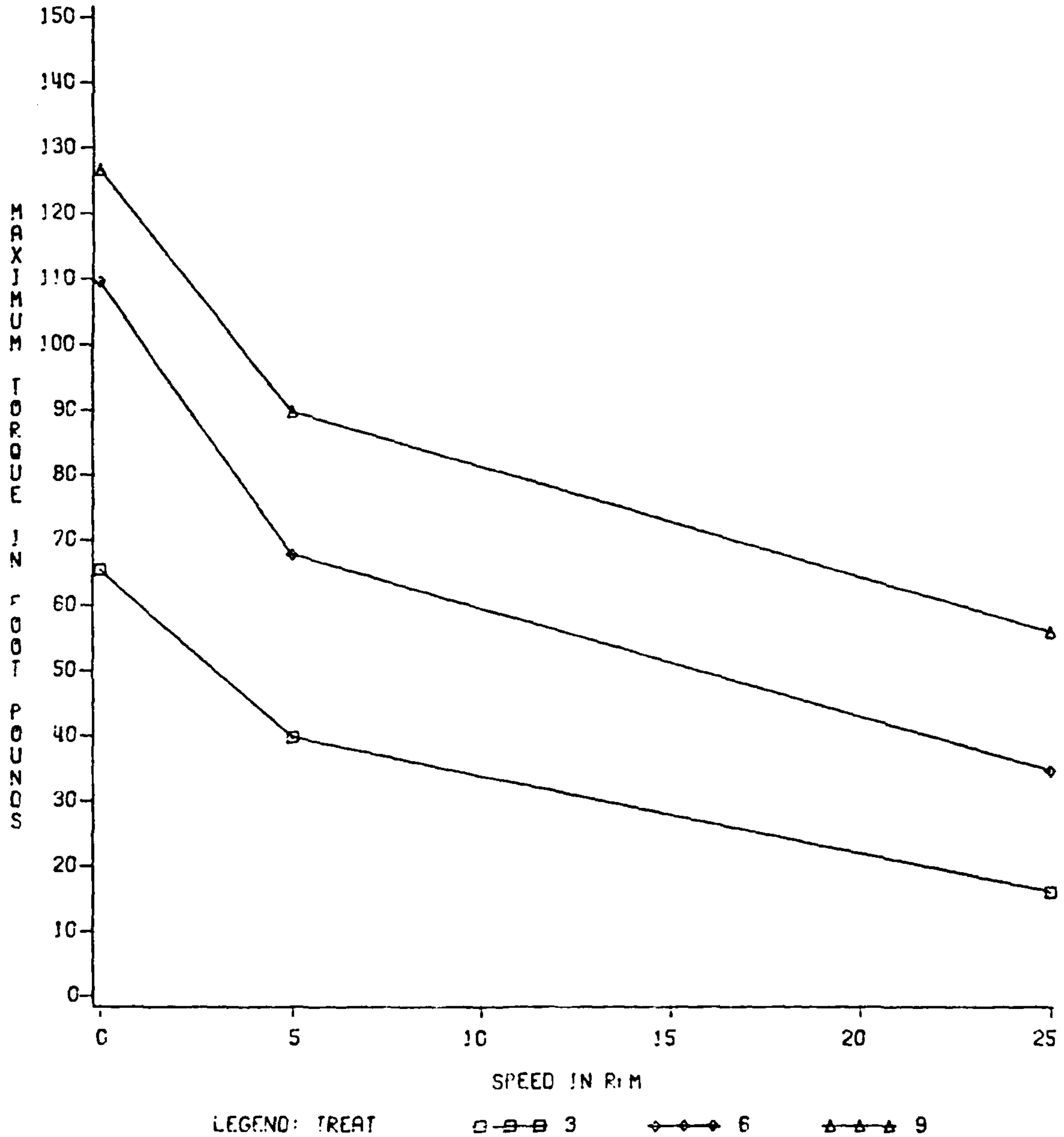

FIGURE 49 MAXIMUM TORQUE VS SPEED FOR KNE AND ROTATION OF 0 DEGREES

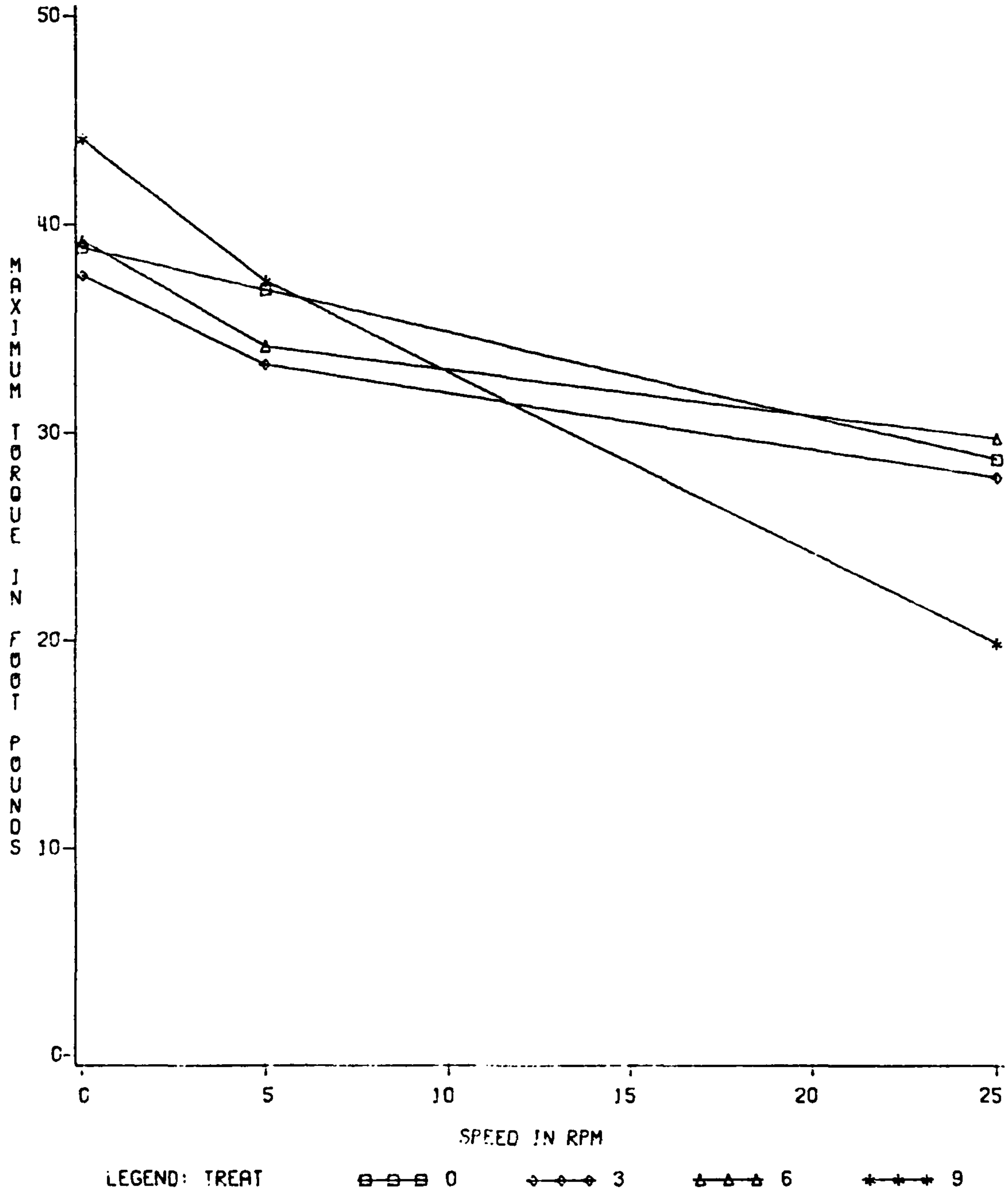

FIGURE 50 MAXIMUM TORQUE VS SPEED FOR VFE AND ROTATION OF −15 DEGREES

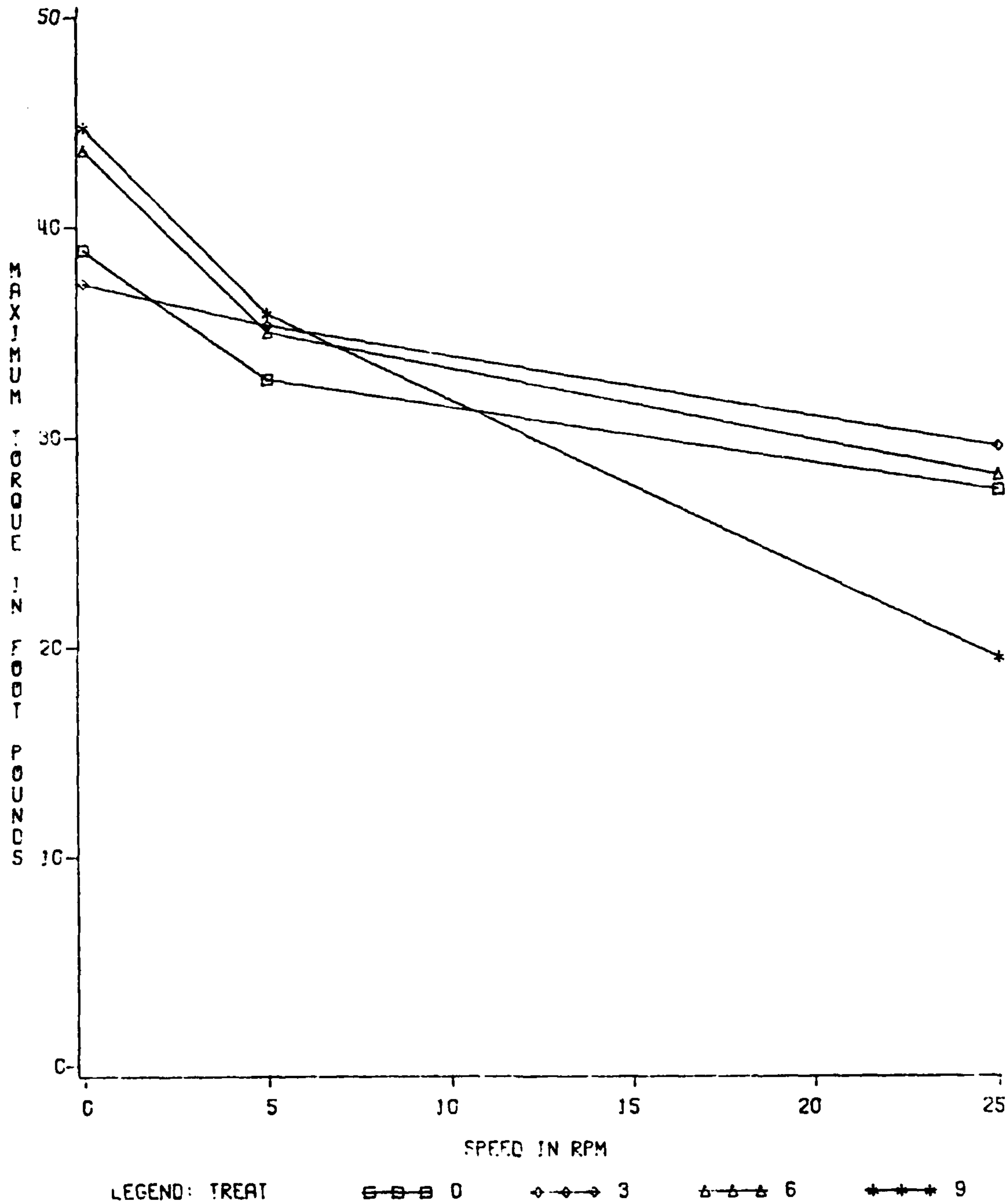

FIGURE 51 MAXIMUM TORQUE VS SPEED FOR VFE AND ROTATION OF −30 DEGREES

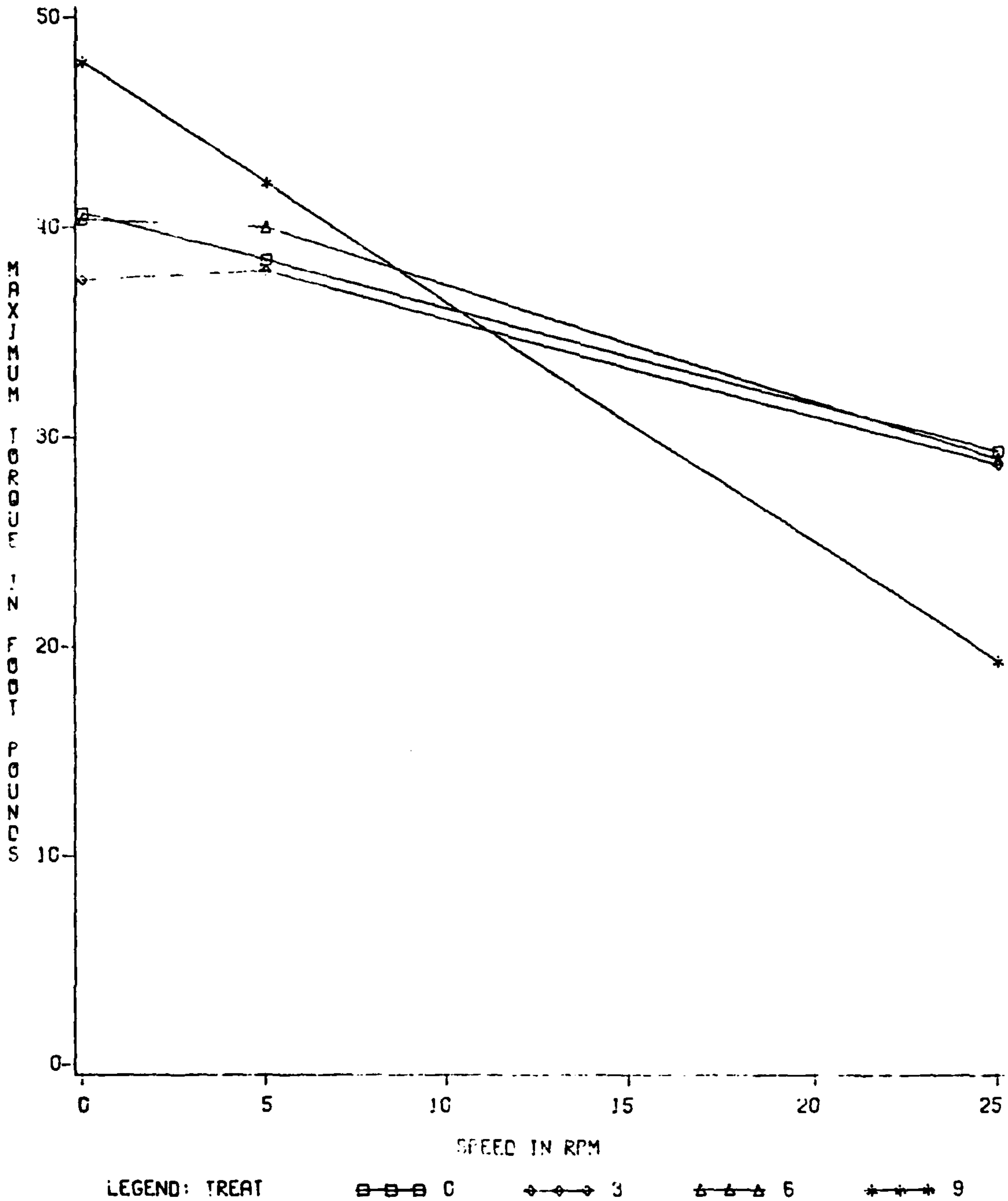

FIGURE 52 MAXIMUM TORQUE VS SPEED FOR VFE AND ROTATION OF 0 DEGREES

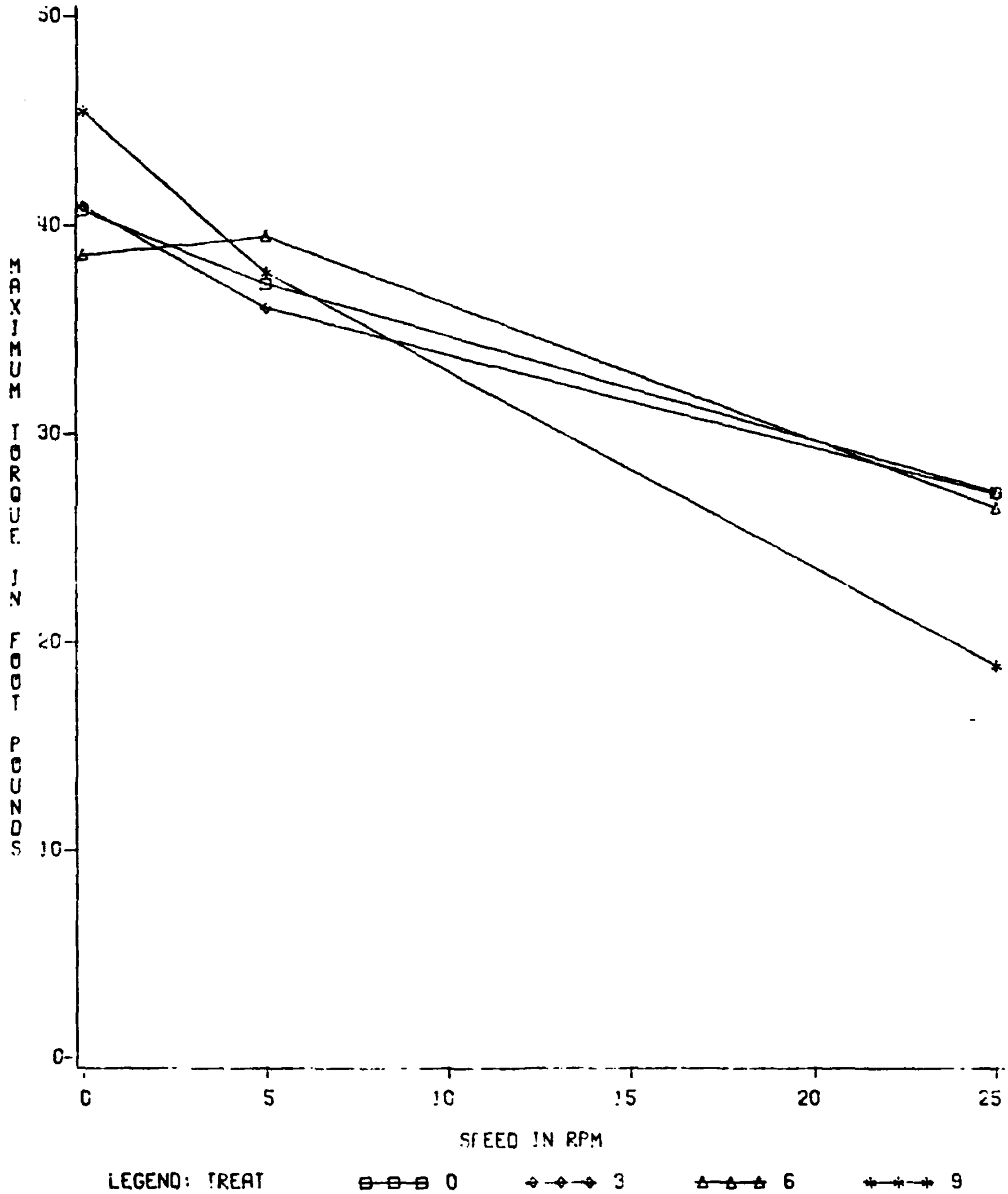

FIGURE 53 MAXIMUM TORQUE VS SPEED FOR VFE AND ROTATION OF 15 DEGREES

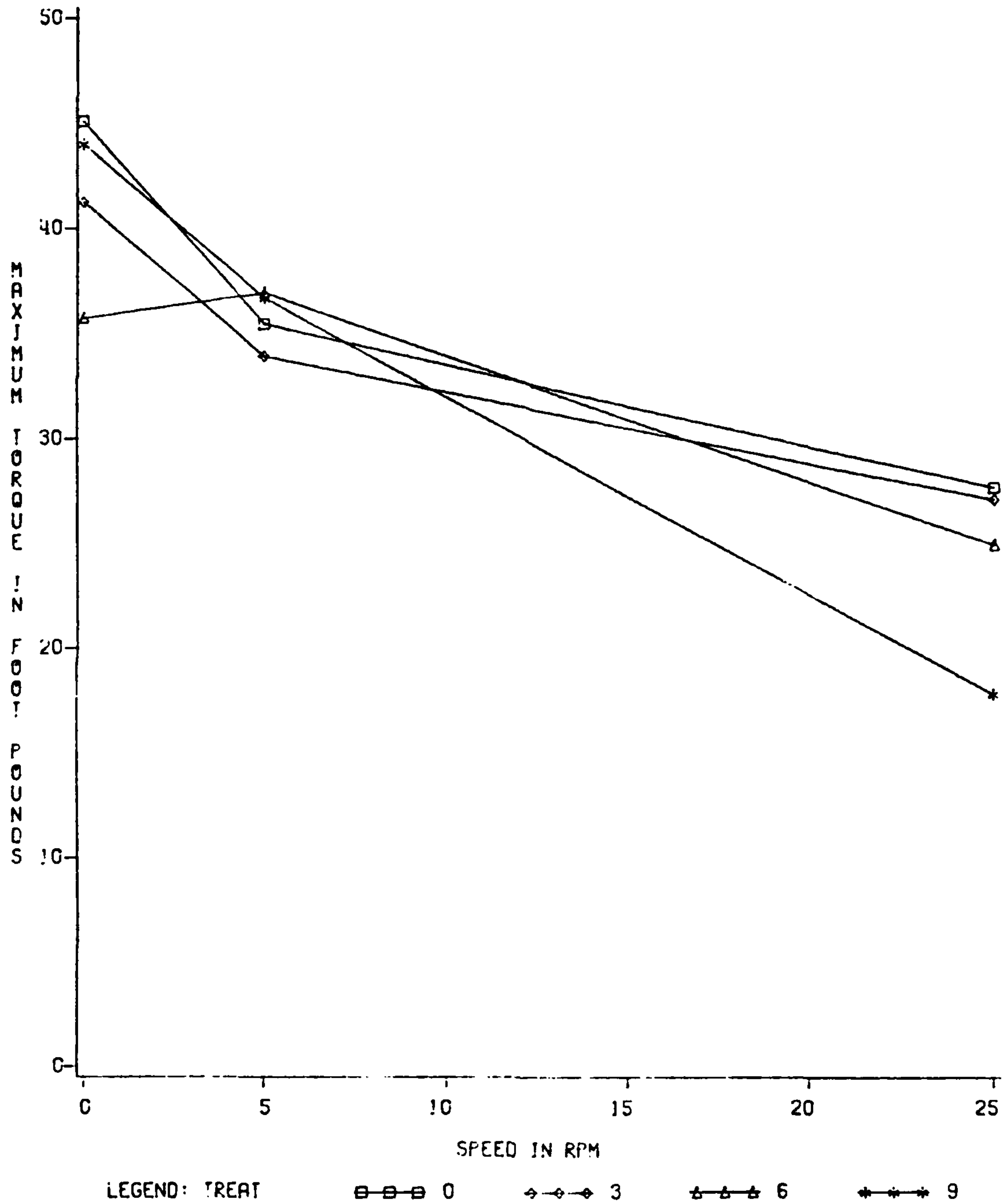

FIGURE 54 MAXIMUM TORQUE VS SPEED FOR VFE AND ROTATION OF 30 DEGREES

The third reason is the vertical flexion at the shoulder (VFE) which did not show the decrease in maximum torque in going from the static to the five RPM condition. Inspection of the plots in Figures 52, 53 and 54 suggest the static values for the 60 degree start are low. During the course of the study, the subjects performed the zero rotation before the positive rotations. The negative rotations were performed after the positve rotations. The subjects initially tended to bend the arm at the elbow while flexing at the shoulder during static contractions resulting in lower torques as measured by the apparatus. With the practice acquired prior to performing the negative rotations, the subject's performance appeared to improve on the static contractions in question (by learning how to apply the forces without bending their arms at the elbow).

Rotation and Joint

The various angles of rotation produced no substantial differences in maximum torque. Only the hip showed any effect with the maximum torque decreasing as the hip was abducted from the sagittal plane.

Maximum torques associated with the joints reflected the size of the muscle groups acting on them. Those joints in which muscles of larger mass were used were observed to have larger torques (BAC, HIP, KNE). Similarly, the joints which involve muscles of smaller mass yielded smaller torques (ELB, ABD, HFE, VFE).

Starting angle

The effect of the various starting angles is to reduce the range of motion allowed to the subject. For the elbow and

shoulder motions (ELB, ABD, HFE, VFE), the range of motion decreased as the starting angle changed from 0 to 30 to 60 to 90 degrees. For the remaining conditions (BAC, HIP, KNE) the range of motion decreased as the starting angle changed from 90 to 60 to 30 degrees.

A general tendency was for the maximum torque to decrease as the range of motion decreased for the back, hip, knee, and horizontal flexion at the shoulder (Figure 37, 43, 46, 49 as examples). No substantial effect was observed for the elbow, abduction at the shoulder, or vertical flexion of the shoulder (Figure 36, 40, 52). In the latter case, the torques tended to bunch up with spreads too small to be considered substantial while the torques were relatively wide spread in the former case.

One other observation is the relatively low torque associated with the 25 RPM speed and the shortest range of motion (30 degrees). At the high speed, a large portion of the range of motion is consumed in simply "catching" the resistance of the apparatus thereby allowing a torque to be measured. The result is that only a small part of the range of motion is still available to the subject to achieve his maximum torque.

<u>Maximum Torque Angle</u>

As the speed of motion increased, the angle at which the subject attained the maximum torque approached the termination point of the range of motion (Figures 55 - 61). An explanation is that the subject must use more of the range of motion to "catch" the dynamometer arm before he can register any torque.

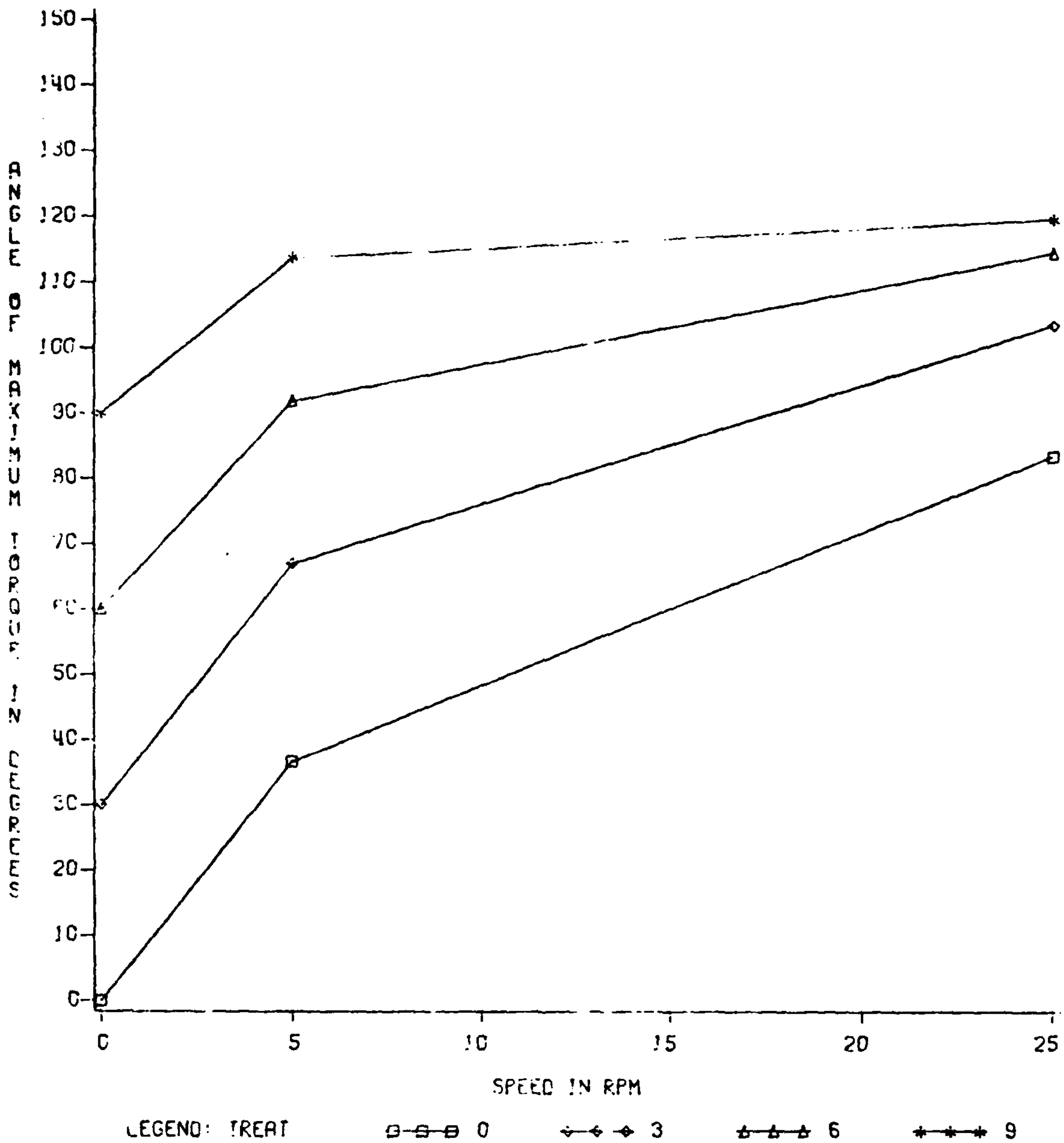

FIGURE 55 ANGLE OF MAXIMUM TORQUE VS SPEED FOR ABD AND ROTATION OF 0 DEGREES

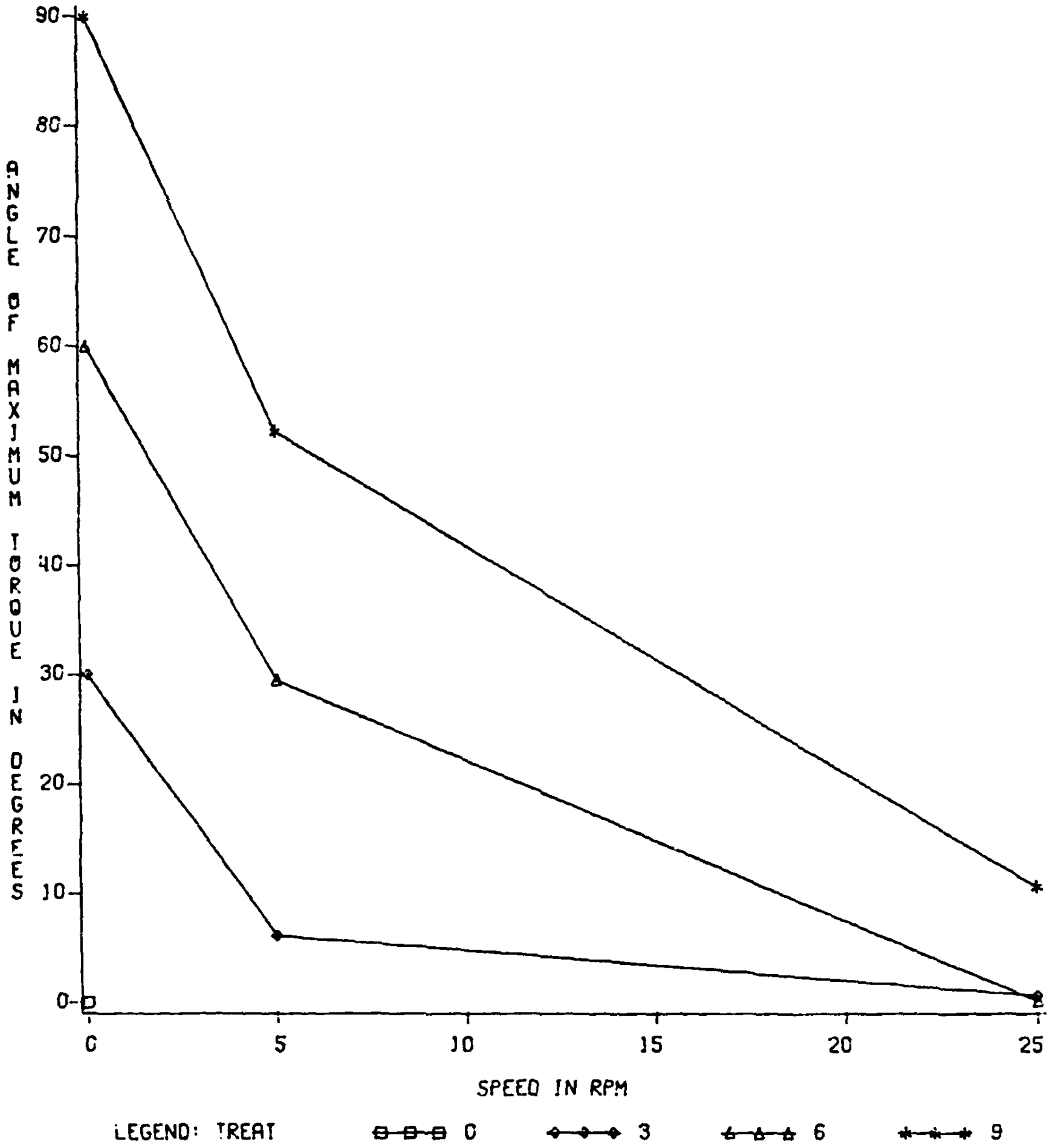

FIGURE 56 ANGLE OF MAXIMUM TORQUE VS SPEED FOR BAC AND ROTATION OF 0 DEGREES

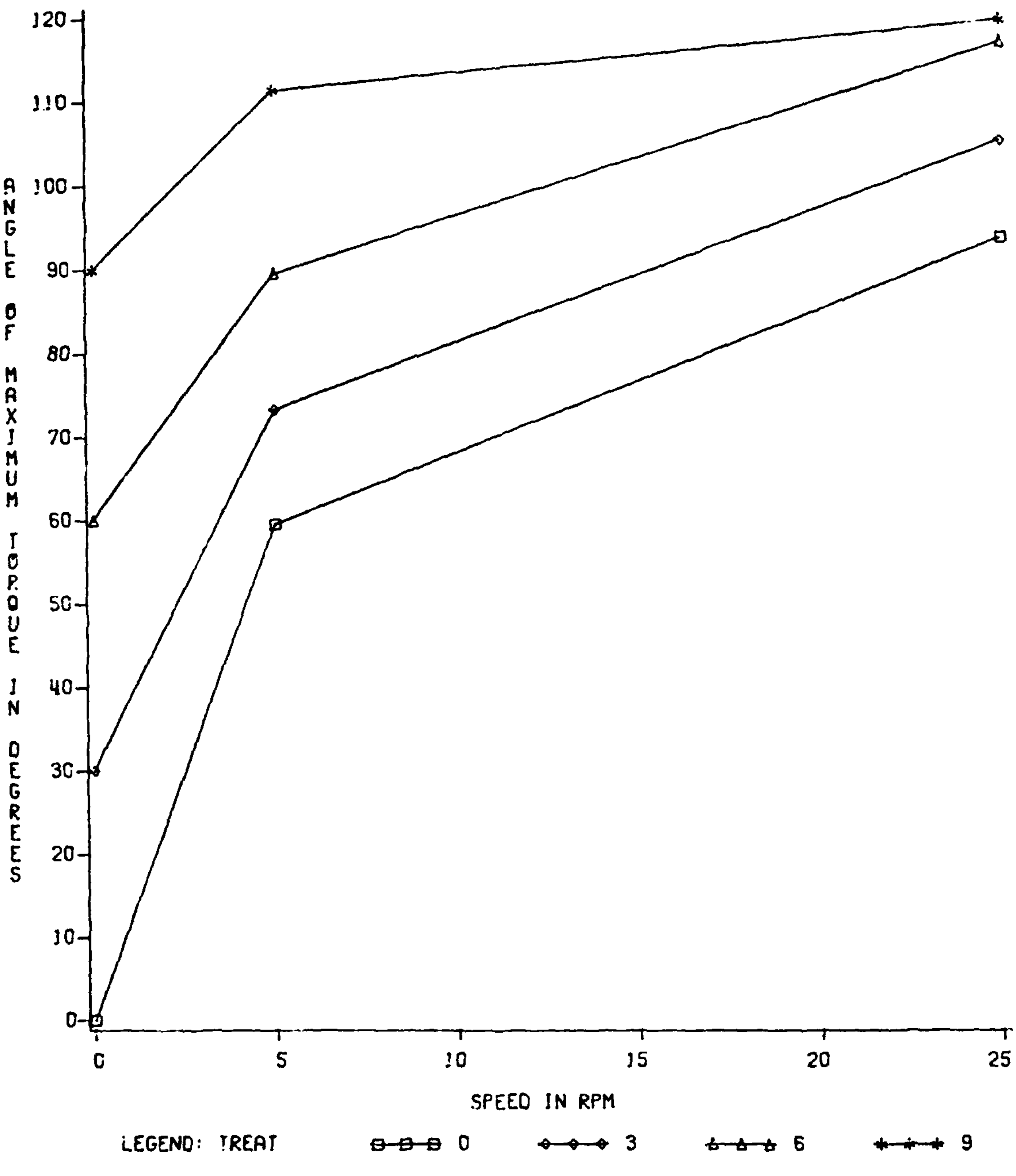

FIGURE 57 ANGLE OF MAXIMUM TORQUE VS SPEED FOR ELB AND ROTATION OF 0 DEGREES

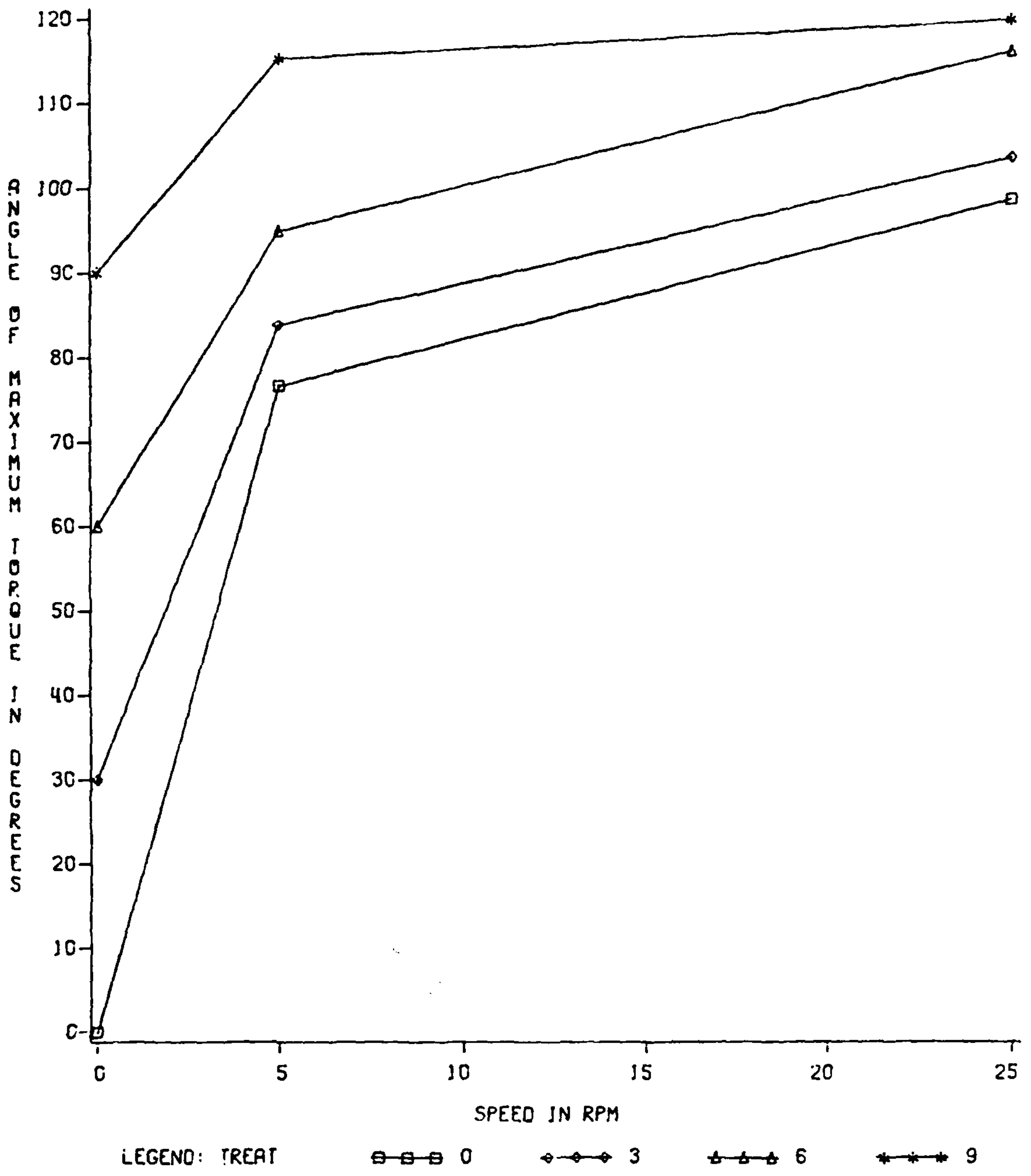

FIGURE 58 ANGLE OF MAXIMUM TORQUE VS SPEED FOR HFE AND ROTATION OF 0 DEGREES

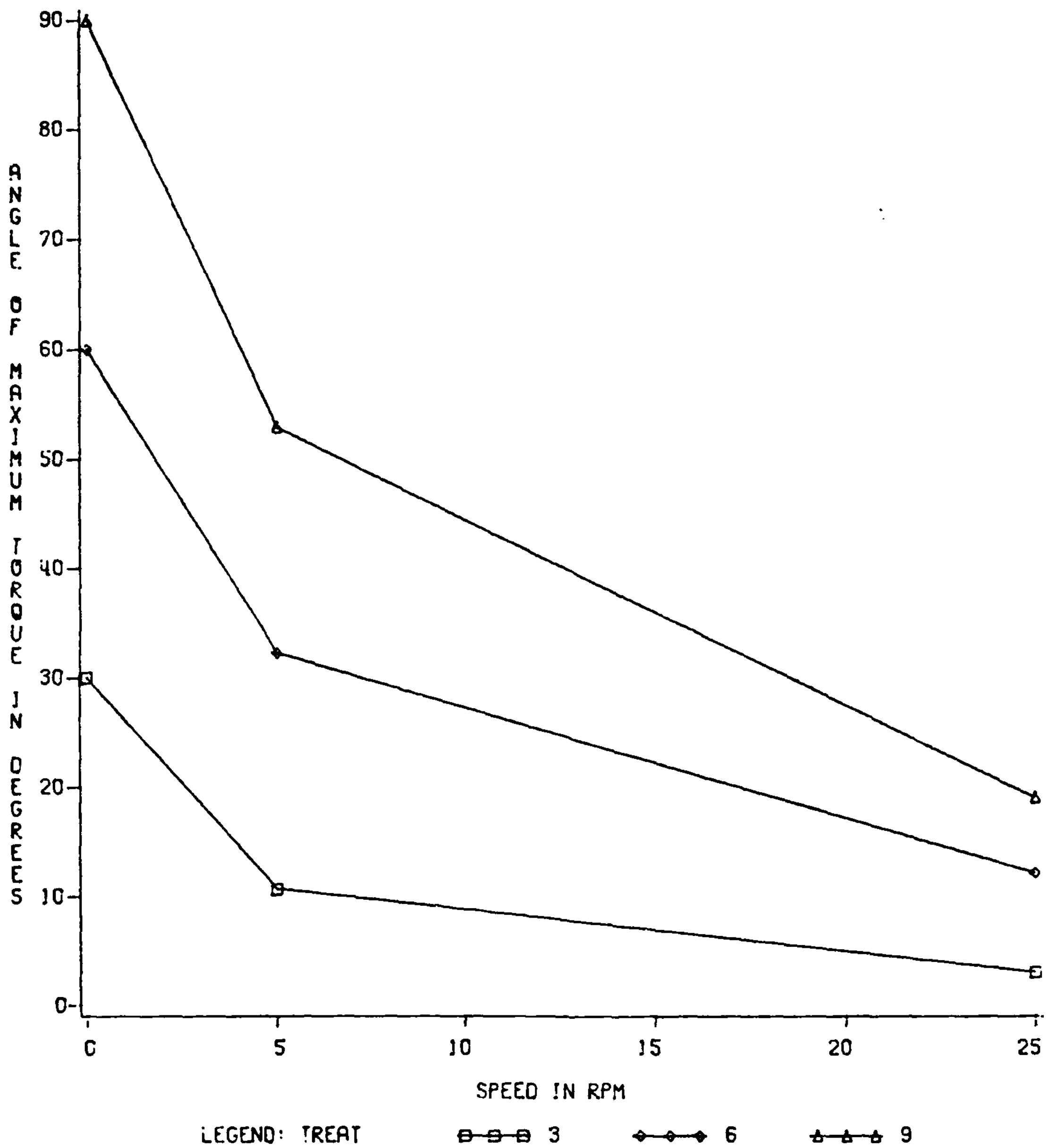

FIGURE 59 ANGLE OF MAXIMUM TORQUE VS SPEED FOR HIP AND ROTATION OF 0 DEGREES

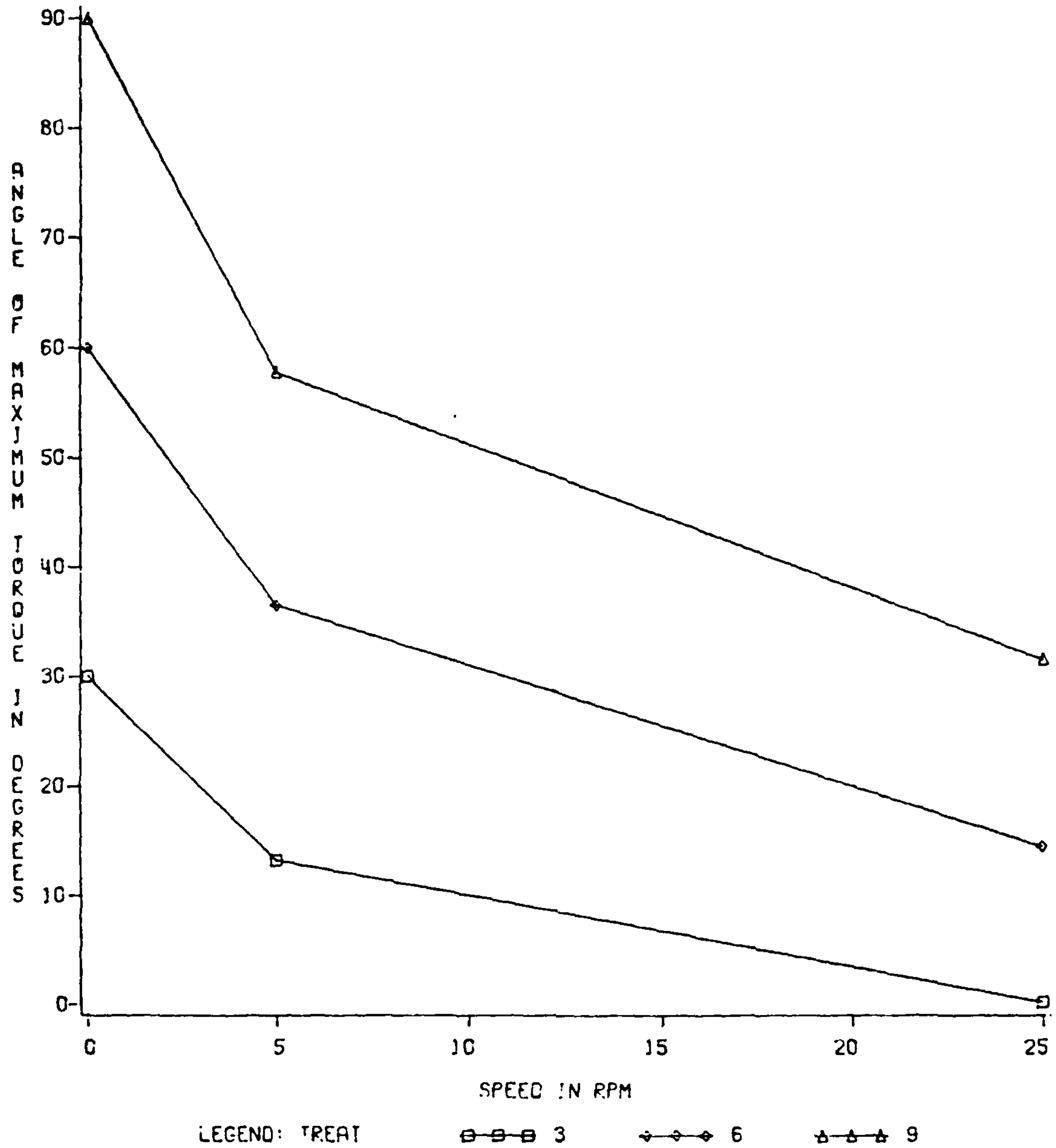

FIGURE 60 ANGLE OF MAXIMUM TORQUE VS SPEED FOR KNE AND ROTATION OF 0 DEGREES

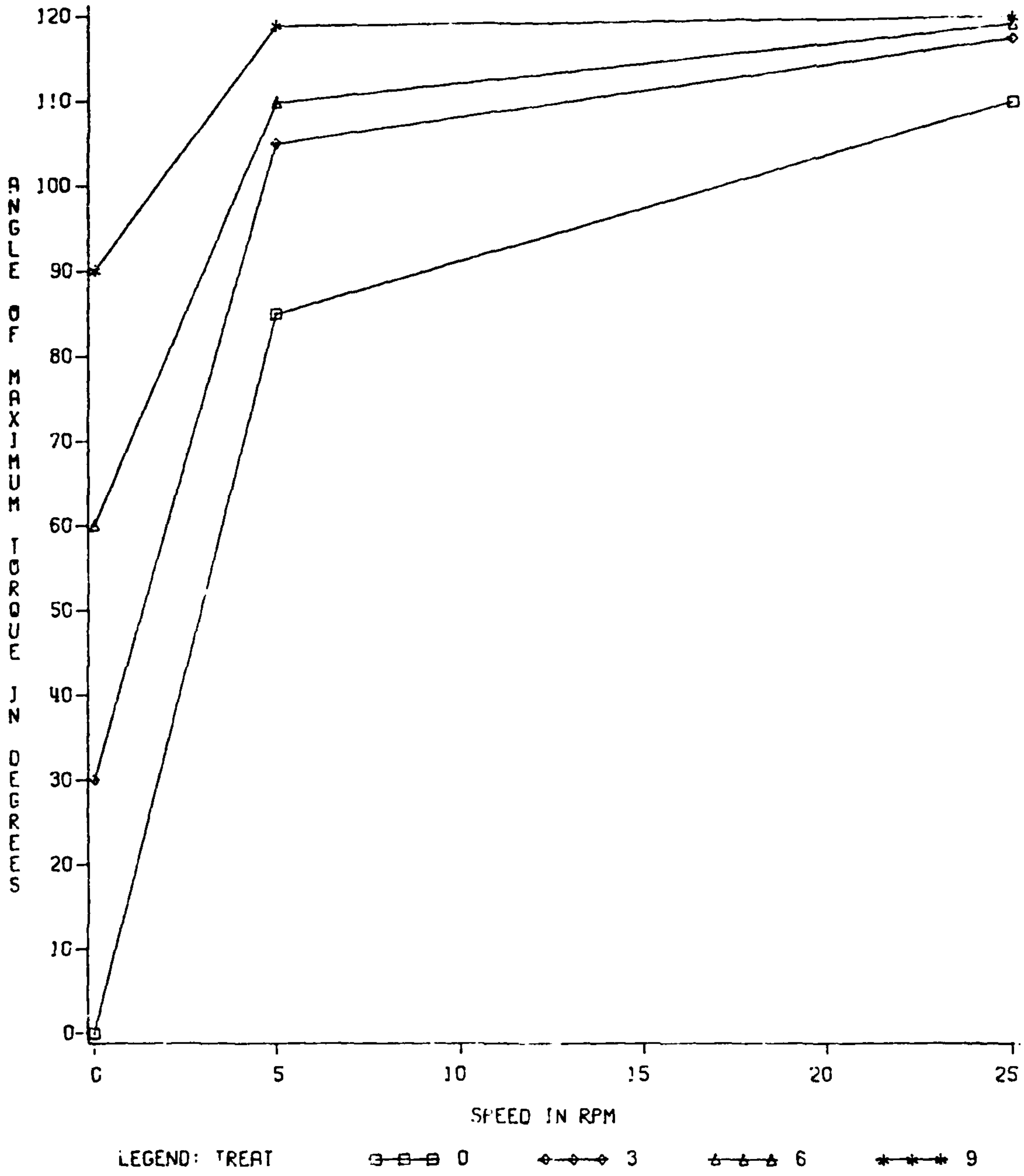

FIGURE 61 ANGLE OF MAXIMUM TORQUE VS SPEED FOR VFE AND ROTATION OF 0 DEGREES

This means he must travel farther before he is able to reach his maximum torque.

Additionally the angle of the maximum torque also moves closer to the finish of the range of motion as the range of motion is decreased. The obvious explanation is that the range of motion is limited by moving the starting position closer to the terminal end of the range of motion. This of course forces the maximum torque to be confined in smaller ranges which are closer to the finish of the range of motion.

The difference in degrees between the angle at which the maximum torque occurred and the starting angle is defined as the angular displacement for the body segment being tested. The angular displacement was observed to increase when the speed of motion increased. (Figures 62-68). This observation seems to stem from the increased displacement required to catch the apparatus to produce a measured torque. Also the angular displacement was seen to decrease as the starting position approached the finish of the range of motion.

Correlation of Static and Dynamic Strength

The set of correlation matrices used in this analysis are presented in Tables 15 through 20. Entries are by joint/speed combinations, ELB at 0 RPM by VFE at 0 RPM produced a Pearson Product Moment Correlation coefficient of .33162 (Table 15). Three values are given for each correlational component; the value of r, the probability associated with that r, and the number of observations used in computing r. Thus, for the entry points described above (ELB/0 and VRD/0), the tabled values are

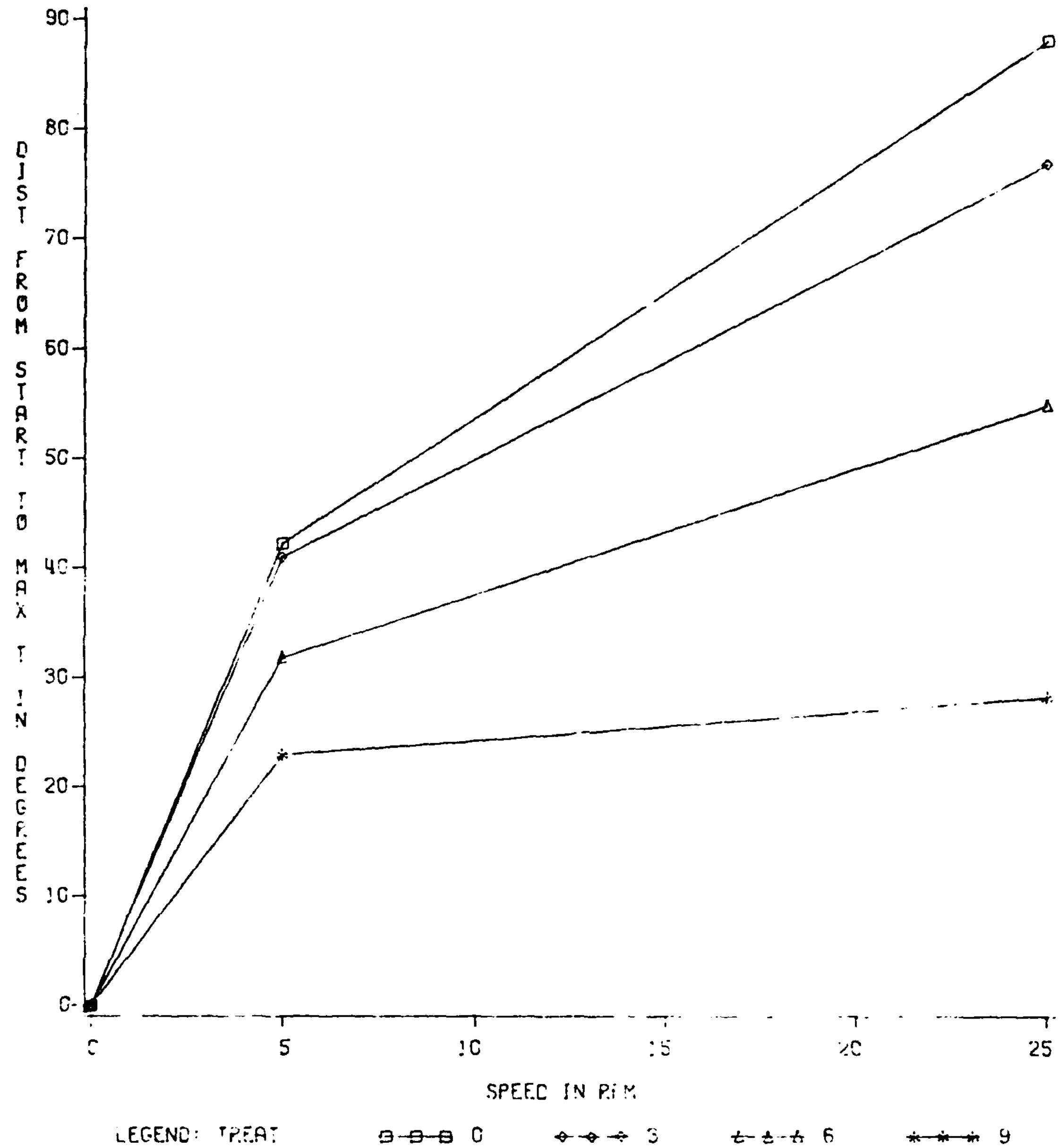

FIGURE 62 DISTANCE FROM START TO MAXIMUM TORQUE VS SPEED FOR ABD AND 0 DEGREES ROTATION

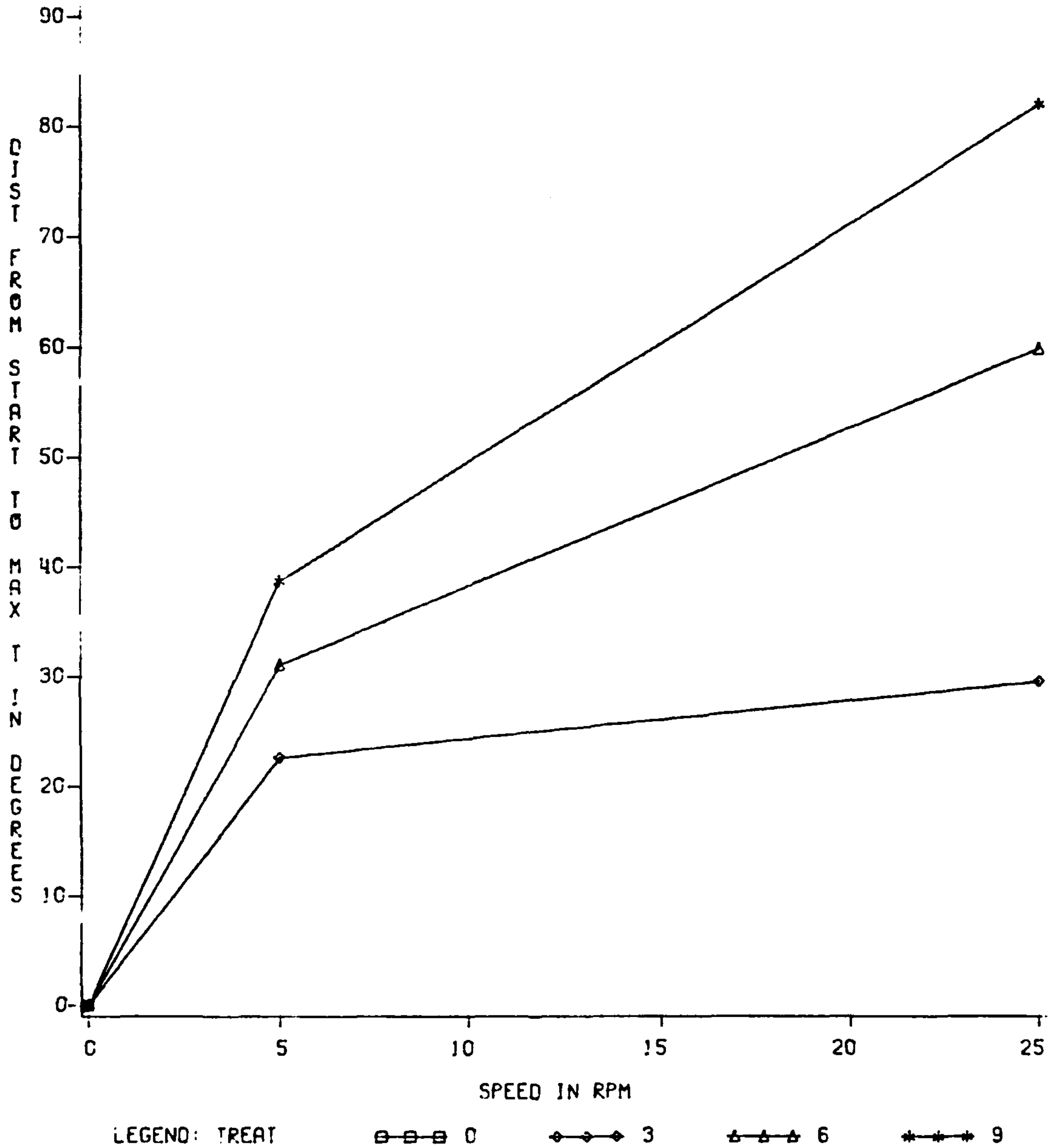

FIGURE 63 DISTANCE FROM START TO MAXIMUM TORQUE VS SPEED FOR BAC AND 0 DEGREES ROTATION

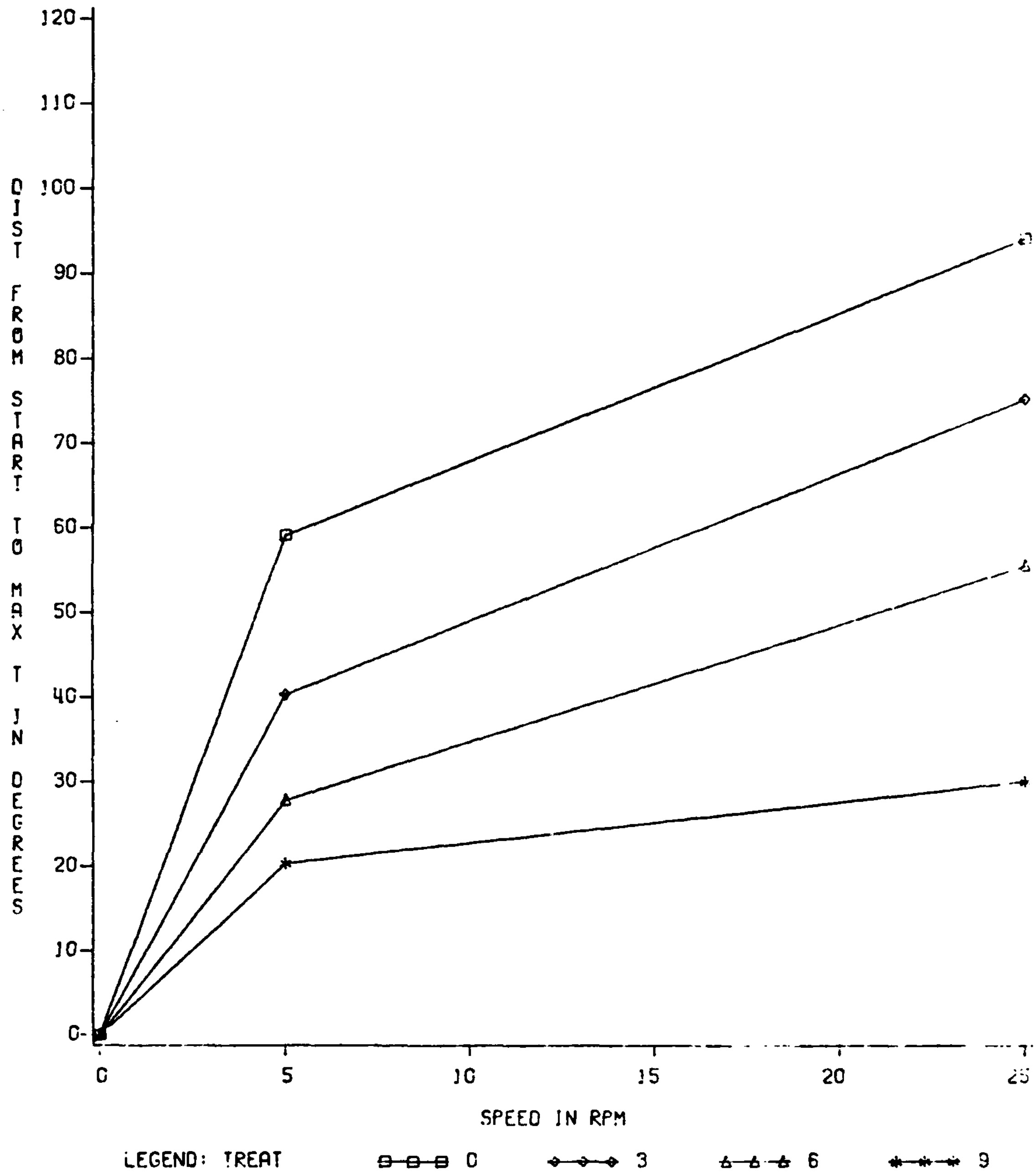

FIGURE 64 DISTANCE FROM START TO MAXIMUM TORQUE VS SPEED FOR ELB AND 0 DEGREES ROTATION

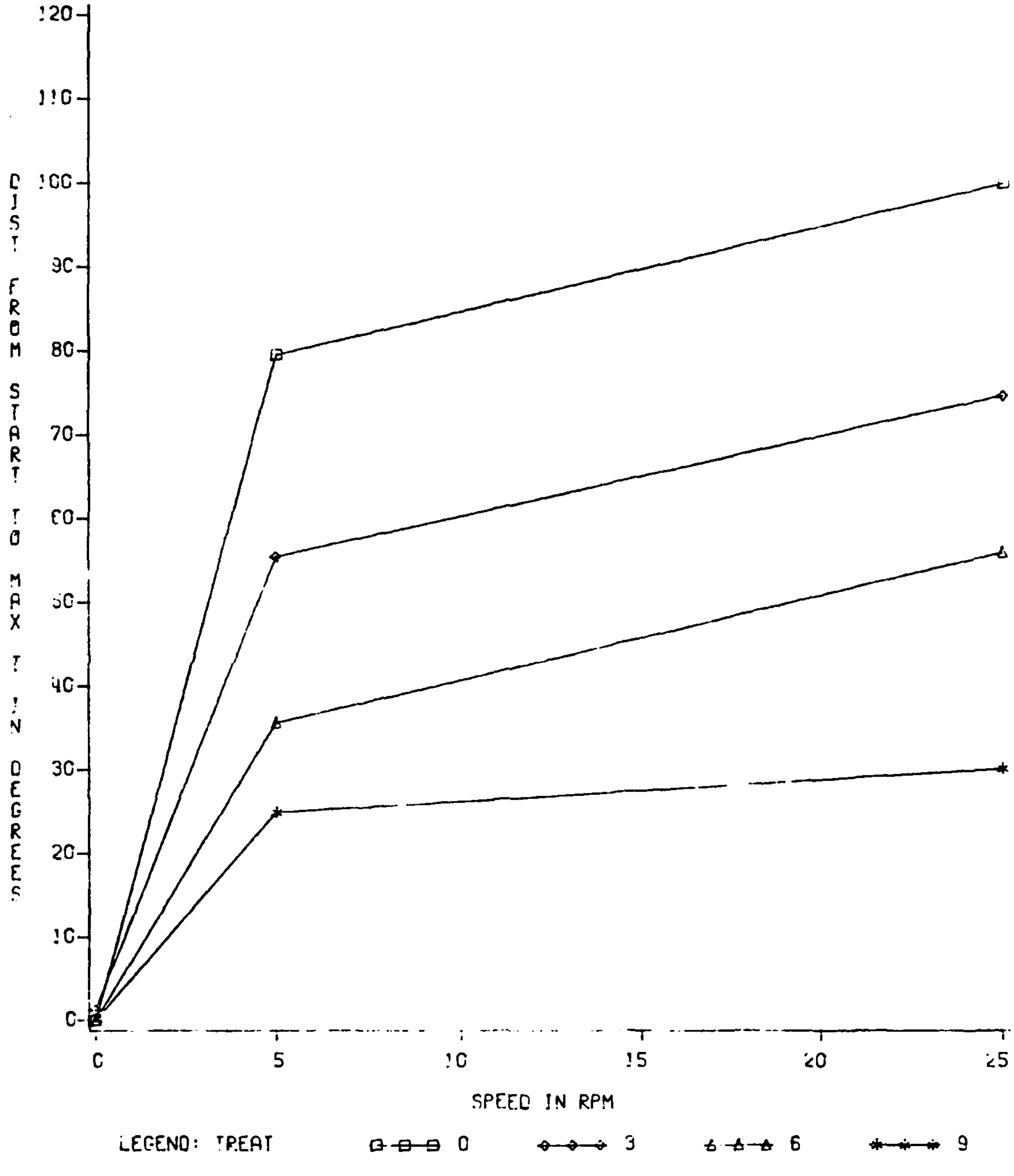

FIGURE 65 DISTANCE FROM START TO MAXIMUM TORQUE VS SPEED FOR HFE AND 0 DEGREES ROTATION

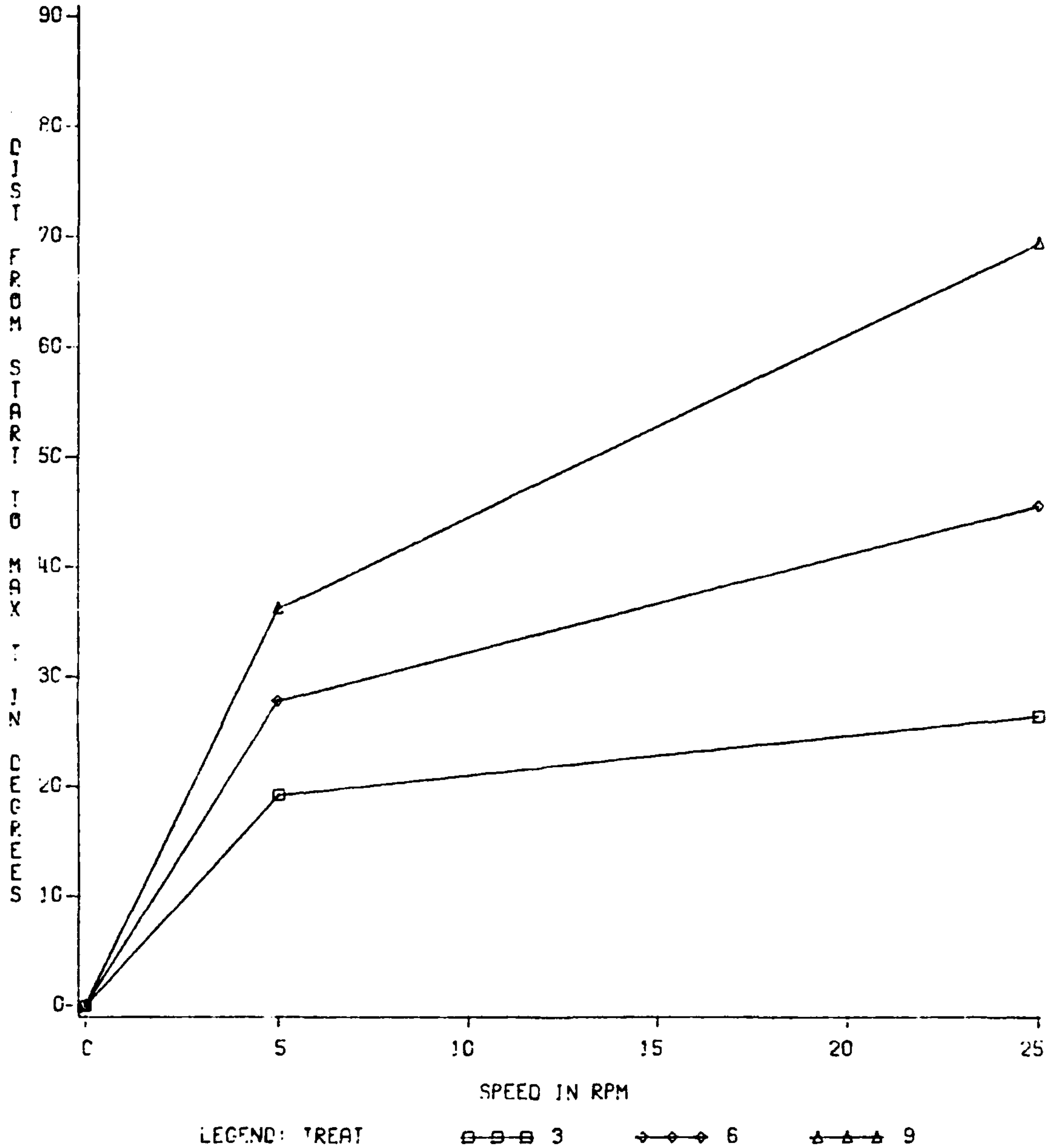

FIGURE 66 DISTANCE FROM START TO MAXIMUM TORQUE VS SPEED FOR HIP AND 0 DEGREES ROTATION

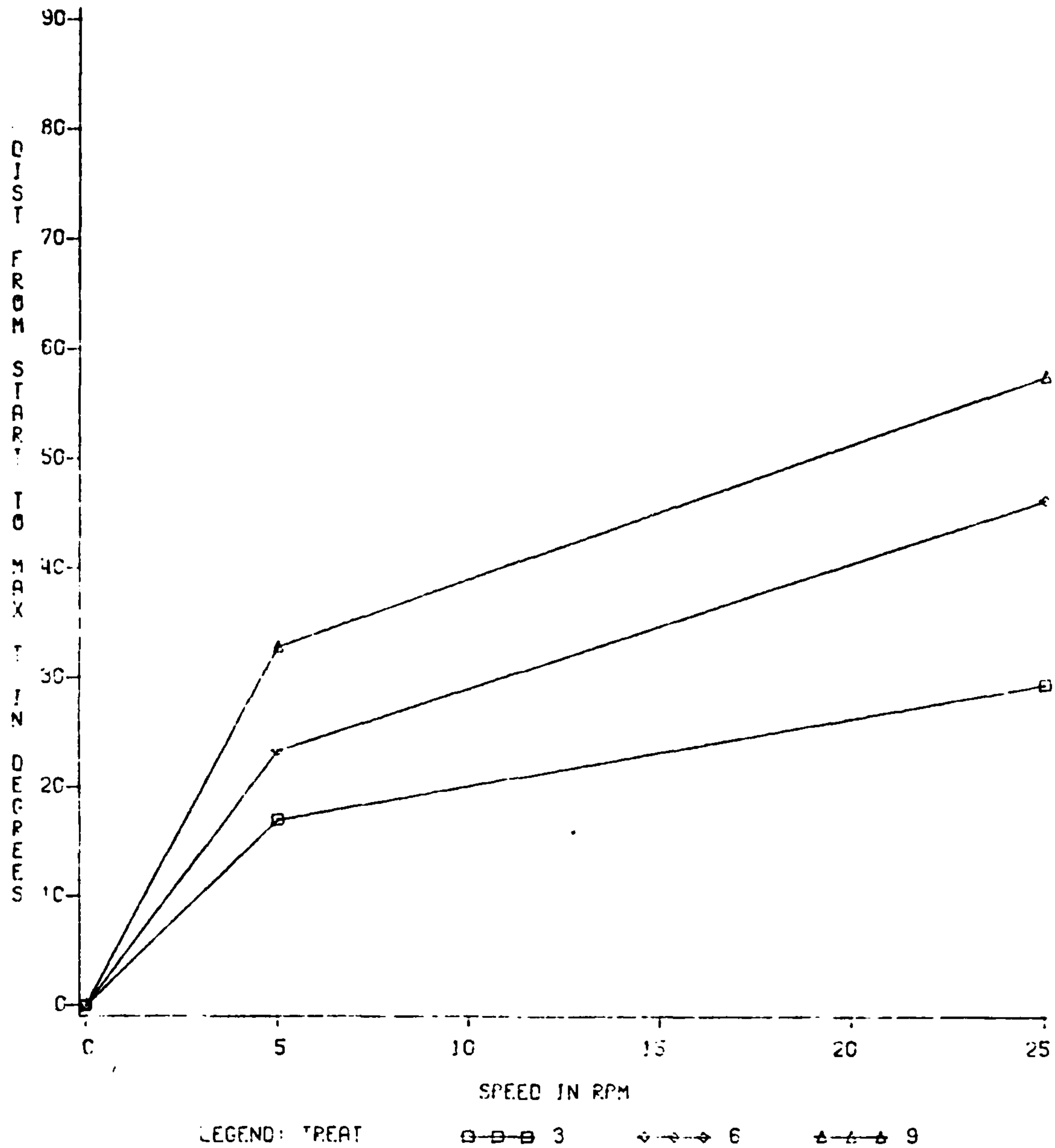

FIGURE 67 DISTANCE FROM START TO MAXIMUM TORQUE VS SPEED FOR KNE AND 0 DEGREES ROTATION

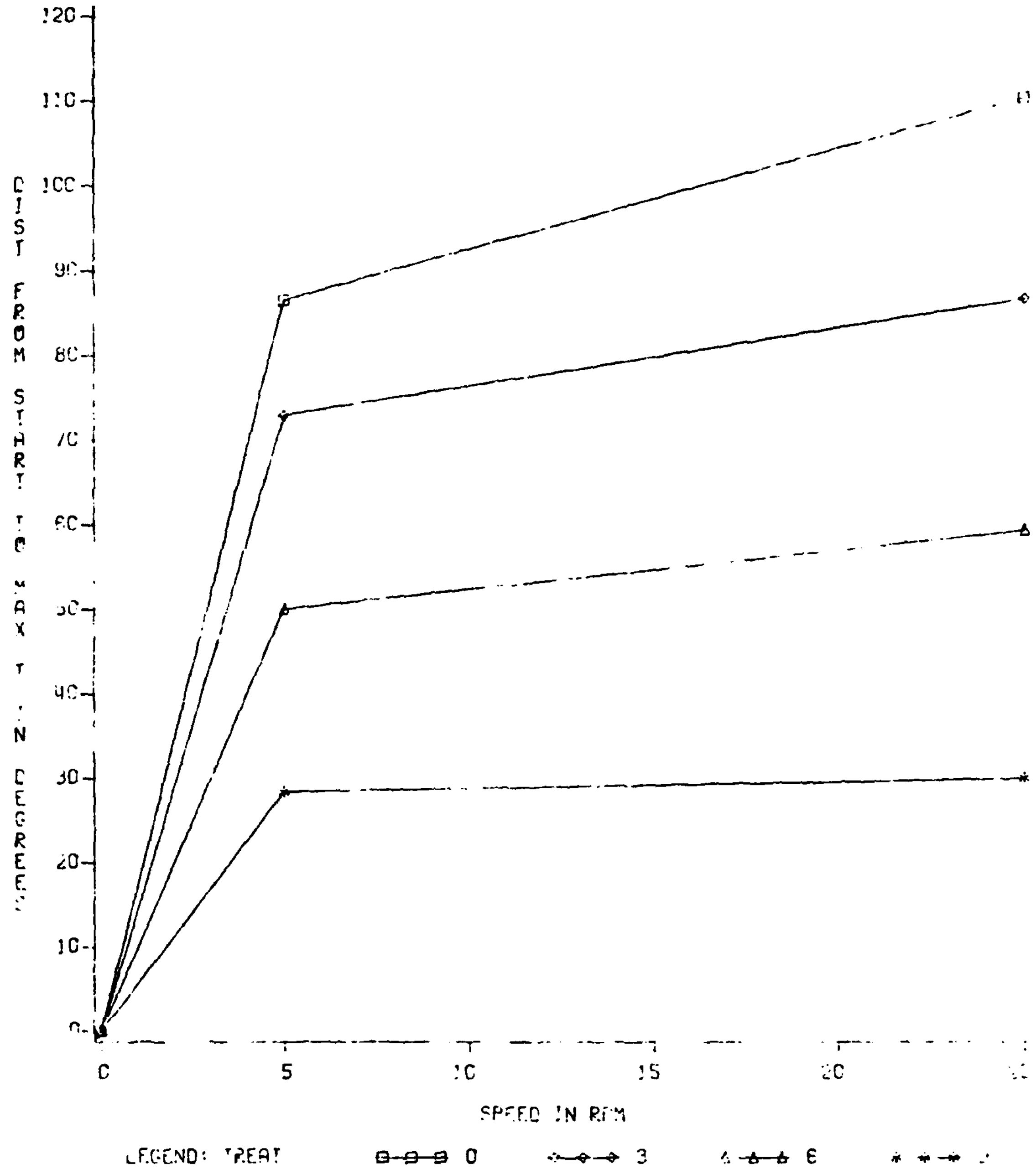

FIGURE 68 DISTANCE FROM START TO MAXIMUM TORQUE VS SPEED FOR VFE AND 0 DEGREES ROTATION

TABLE 15. Correlation coefficients for 0 RPM by RPM

	ELBO	VFEO	HFEO	ABDO	BACO	HIPO	KNEO
ELBO	1.00000 0.0000 1476	0.33162 0.0001 1446	0.56946 0.0001 300	-0.13145 0.0228 300	0.18405 0.0014 297	0.36942 0.0001 609	0.19762 0.0001 654
VFEO	0.33162 0.0001 1446	1.00000 0.0000 1470	0.24096 0.0001 300	0.41121 0.0001 300	0.12154 0.0363 297	0.30743 0.0001 612	0.37140 0.0001 642
HFEO	0.56946 0.0001 300	0.24096 0.0001 300	1.00000 0.0000 300	0.10927 0.0587 300	0.26948 0.0001 297	0.49737 0.0001 213	0.32934 0.0001 222
ABDO	-0.13145 0.0228 300	0.41121 0.0001 300	0.10927 0.0587 300	1.00000 0.0000 300	0.06074 0.2968 297	0.05188 0.4513 213	0.06891 0.3067 222
BACO	0.18405 0.0014 297	0.12154 0.0363 297	0.26948 0.0001 297	0.06074 0.2968 297	1.00000 0.0000 297	0.19787 0.0040 210	0.20288 0.0026 219
HIPO	0.36942 0.0001 609	0.30743 0.0001 612	0.49737 0.0001 213	0.05188 0.4513 213	0.19787 0.0040 210	1.00000 0.0000 615	0.40931 0.0001 606
KNEO	0.19762 0.0001 654	0.37140 0.0001 642	0.32934 0.0001 222	0.06891 0.3067 222	0.20288 0.0026 219	0.40931 0.0001 606	1.00000 0.0000 660

.33162 for r, .0001 as the probability the null hypothesis is true, and 300 is the number of observations used in the computation of r.

Many of the correlations are statistically significant in that their probabilities are less than the .05 criterion yet the value of r is small, some less than .3. This is attributed to the large numbers of observations used. For this analysis only the values of $r \geq .3$ were considered worth noting. The coefficient of determination, the square of the correlation coefficient, for values of r = .3 is .09. This indicates only 9% of the variance is associated. Anything less than this amount is simply too small to be of any practical consideration.

Correlations of Strengths Within Speeds

No consistant pattern is apparent for the static condition (Table 15). The elbow correlated significantly with two of the shoulder motions (VFE and HFE) and one of the extensions (HIP). Only the VFE and ABD correlated well within the shoulder group. And the VFE and HFE combinations correlated with both the HIP and KNE extensions. Within the extension group only the HIP and KNE had significant correlations. The strength measurements for the back had no significant correlations.

At the slow speed, 5 RPM, a pattern seems to be emerging (Table 16). The flexions (ELB, VFE, HFE) and the extensions (BAC, HIP, KNE) appear to be excluding each other. Again the elbow correlates with two of the shoulder motions, but none of the extensions. The VFE still correlates with the hip while the HFE has no significant correlations with the extensions. For

TABLE 16. Correlation coefficients for 5 RPM by 5 RPM

	ELB5	VEE5	HEL5	ABD5	BAC5	HIP5	KNE5
ELB5	1.00000 0.0000 1479	0.35999 0.0001 1458	0.46653 0.0001 291	0.25297 0.0001 297	-0.13053 0.0505 225	0.10733 0.0083 603	0.02874 0.4652 648
VEE5	0.35999 0.0001 1458	1.00000 0.0000 1479	0.46599 0.0001 291	0.42604 0.0001 297	0.27550 0.0001 225	0.36337 0.0001 603	0.19748 0.0001 645
HEL5	0.46653 0.0001 291	0.46599 0.0001 291	1.00000 0.0000 291	0.42353 0.0001 288	0.25957 0.0001 222	0.28766 0.0001 213	0.17250 0.0105 219
ABD5	0.25297 0.0001 297	0.42604 0.0001 297	0.42353 0.0001 288	1.00000 0.0000 297	0.16092 0.0164 222	0.35609 0.0001 213	0.15320 0.0234 219
BAC5	-0.13053 0.0505 225	0.27550 0.0001 225	0.25957 0.0001 222	0.16092 0.0164 222	1.00000 0.0000 225	0.20123 0.0030 216	0.34686 0.0001 222
HIP5	0.10733 0.0083 603	0.36337 0.0001 603	0.28766 0.0001 213	0.35609 0.0001 213	0.20123 0.0030 216	1.00000 0.0000 609	0.54669 0.0001 603
KNE5	0.02874 0.4652 648	0.19748 0.0001 645	0.17250 0.0105 219	0.15320 0.0234 219	0.34686 0.0001 222	0.54669 0.0001 603	1.00000 0.0000 660

this condition, the ABD correlates with the other shoulder motions and the HIP. Within the extensions the KNE correlates with the BAC and HIP, but the BAC does not correlate well with the HIP.

The most obvious pattern shows up in the high speed, 25 RPM, condition (Table 17). The elbow and shoulder combinations all had significant correlations. Also, the extensions all correlated very well with each other. Although only two correlations were signifiacnt (ELB with both the BAC and KNE), the correlations between the upper body and the lower body were all negative. Part of this is due to the opposite direction of the motion. The upper body motions were flexions and abductions while the lower body motions were all extensions.

Correlations of Strengths Between Speeds

One general trend is the strong tendancy for a joint to correlate well with itself at different speeds. This is true when the speeds are relatively the same as in the 0 and 5 RPM (Table 18) and the 5 and 25 RPM (Table 19) comparisons. However, when the disparity between the speeds is larger, the tendancy becomes less discernable (Table 20).

Overall the correlations of the flexions and extensions tend to be low across the speed changes while the correlations within like motions tend to be better (Tables 18 and 19). Again the larger the disparity in the speed, the more tenuous becomes the pattern (Table 20).

The back correlated poorly in almost all comparisons. Only the high speed and slow speed correlations for the HIP and KNE provide exceptions (Table 20).

TABLE 17. Correlation coefficients for 25 RPM by 25 RPM

	ELB25	VPE25	HPE25	ABD25	BAC25	HIP25	KNE25
ELB25	1.00000 0.0000 1475	0.63403 0.0001 1452	0.49125 0.0001 300	0.50503 0.0001 297	-0.40121 0.0001 222	-0.29337 0.0001 621	-0.40361 0.0001 656
VPE25	0.63403 0.0001 1452	1.00000 0.0000 1473	0.54407 0.0001 300	0.67006 0.0001 297	-0.27262 0.0001 222	-0.17700 0.0001 618	-0.26723 0.0001 645
HPE25	0.49125 0.0001 300	0.54407 0.0001 300	1.00000 0.0000 300	0.43718 0.0001 297	-0.10026 0.1364 222	-0.04797 0.4801 219	-0.05934 0.3822 219
ABD25	0.50503 0.0001 297	0.67006 0.0001 297	0.43718 0.0001 297	1.00000 0.0000 297	-0.21196 0.0016 219	-0.10921 0.1095 216	-0.11656 0.0875 216
BAC25	-0.40121 0.0001 222	-0.27262 0.0001 222	-0.10026 0.1364 222	-0.21196 0.0016 219	1.00000 0.0000 222	0.75374 0.0001 216	0.74491 0.0001 216
HIP25	-0.29337 0.0001 621	-0.17700 0.0001 618	-0.04797 0.4801 219	-0.10921 0.1095 216	0.75374 0.0001 216	1.00000 0.0000 621	0.73646 0.0001 609
KNE25	-0.40361 0.0001 656	-0.26723 0.0001 645	-0.05934 0.3822 219	-0.11656 0.0875 216	0.74491 0.0001 216	0.73646 0.0001 609	1.00000 0.0000 660

TABLE 18. Correlation coefficients for 0 RPM by 5 RPM

	ELB5	VFE5	HFE5	ABD5	BAC5	HIP5	KNE5
ELB0	0.40579 0.0001 1461	0.33869 0.0001 1458	0.40716 0.0001 291	-0.02178 0.7086 297	0.13043 0.0507 225	0.31250 0.0001 603	0.23532 0.0001 654
VFE0	0.25263 0.0001 1449	0.49816 0.0001 1452	0.35069 0.0001 291	0.36501 0.0001 297	0.26738 0.0001 225	0.41350 0.0001 606	0.40085 0.0001 645
HFE0	0.38886 0.0001 300	0.29740 0.0001 300	0.54638 0.0001 291	0.16390 0.0046 297	0.18458 0.0055 225	0.17724 0.0090 216	0.13100 0.0513 222
ABD0	0.28903 0.0001 300	0.35847 0.0001 300	0.28767 0.0001 291	0.56100 0.0001 297	0.25235 0.0001 225	0.19461 0.0041 216	-0.01671 0.8044 222
BAC0	0.03723 0.5227 297	0.20839 0.0003 297	0.25158 0.0001 288	0.16078 0.0057 294	0.54233 0.0001 222	0.26136 0.0001 213	0.21355 0.0015 219
HIP0	0.19062 0.0001 609	0.30735 0.0001 609	0.39658 0.0001 210	0.24037 0.0004 210	0.24466 0.0003 213	0.62975 0.0001 600	0.43018 0.0001 609
KNE0	0.03479 0.3766 648	0.19042 0.0001 645	0.33029 0.0001 219	0.17000 0.0117 219	0.30192 0.0001 222	0.45677 0.0001 600	0.66583 0.0001 654

TABLE 19. Correlation coefficients for 0 RPM by 25 RPM

	ELB25	VFE25	HFE25	ABD25	BAC25	HIP25	KNE25
ELB0	0.09656 0.0002 1451	0.10669 0.0001 1449	0.26289 0.0001 300	0.08724 0.1336 297	0.12204 0.0695 222	0.23792 0.0001 615	0.19977 0.0001 654
VFE0	0.09812 0.0002 1446	0.21596 0.0001 1452	0.05951 0.2300 300	0.15316 0.0082 297	0.40086 0.0001 222	0.49011 0.0001 618	0.42302 0.0001 639
HFE0	0.07645 0.1866 300	0.09189 0.1122 300	0.43221 0.0001 300	0.13474 0.0202 297	0.22460 0.0007 222	0.25764 0.0001 219	0.15007 0.0264 219
ABD0	0.38018 0.0001 300	0.42656 0.0001 300	0.35699 0.0001 300	0.52505 0.0001 297	-0.08750 0.1940 222	0.10528 0.1203 219	-0.00573 0.9328 219
BAC0	-0.10340 0.0752 297	0.01570 0.7876 297	0.19480 0.0007 297	-0.04160 0.4773 294	0.34814 0.0001 219	0.28670 0.0001 216	0.25525 0.0001 216
HIP0	-0.01510 0.7086 615	-0.03607 0.3731 612	0.17935 0.0087 213	-0.01312 0.8501 210	0.50335 0.0001 210	0.54290 0.0001 609	0.37251 0.0001 603
KNE0	-0.16738 0.0001 656	-0.10665 0.0066 648	0.04755 0.4809 222	0.03938 0.5622 219	0.49591 0.0001 219	0.61054 0.0001 612	0.65927 0.0001 651

TABLE 20. Correlation coefficients for 5 RPM by 25 RPM

	ELB25	VFE25	HFE25	ABD25	BAC25	HIP25	KNE25
ELB5	0.53702 0.0001 1454	0.43050 0.0001 1452	0.39737 0.0001 300	0.34600 0.0001 297	-0.22636 0.0007 222	0.03088 0.4447 615	-0.05551 0.1581 648
VFE5	0.22419 0.0001 1457	0.38585 0.0001 1461	0.27969 0.0001 300	0.38847 0.0001 297	0.15967 0.0173 222	0.38221 0.0001 615	0.17476 0.0001 645
HFE5	0.18848 0.0012 291	0.30275 0.0001 291	0.53472 0.0001 291	0.36108 0.0001 288	0.17653 0.0088 219	0.27649 0.0001 216	0.24972 0.0002 216
ABD5	0.24329 0.0001 297	0.39564 0.0001 297	0.32829 0.0001 297	0.45064 0.0001 294	-0.01840 0.7865 219	0.20380 0.0026 216	0.11073 0.1046 216
BAC5	-0.13076 0.0501 225	0.13603 0.0415 225	0.13791 0.0387 225	0.18733 0.0051 222	0.43733 0.0001 222	0.33883 0.0001 219	0.46399 0.0001 219
HIP5	-0.10604 0.0088 609	-0.06396 0.1157 606	0.03468 0.5122 216	0.02358 0.7278 213	0.42323 0.0001 213	0.70659 0.0001 600	0.47328 0.0001 597
KNE5	-0.35488 0.0001 656	-0.21363 0.0001 648	-0.13829 0.0049 222	-0.18507 0.0060 219	0.71707 0.0001 219	0.67345 0.0001 615	0.78174 0.0001 654

Anthropometric and Strength Distributions

Raw data for anthropometric measures are presented in Table 21. The first entry in Table 21 is the subject's weight in kilograms. The next two are subject height and acromion height in centimeters. Lengths in centimeters for the shoulder to elbow, forearm-hand length, hand length, and foot length are the next four entries. The remaining entries in Table 21 are circumferences measured in centimeters.

Descriptive statistics are presented in Table 22 for the anthropometry data. Means and standard deviations are included as well as the minimum and maximum values.

Histograms of the distributions of torques for the seven joint combinations at a rotation of zero by the three speeds, 0, 5, and 25 RPM, are presented in Figures 69-75.

The distributions in Figure 69 for abduction at the shoulder appear to be normally distributed. The mode visibly shifts to lower torques as the speed changes to higher RPM's.

In Figure 70, the distribution for extension of the back, a different pattern appears. The distributions for the 0 and 5 RPM conditions appear to be normally distributed however no real shift of torque seems to occur. The distribution for the 25 RPM is bi-modal and shows no real pattern, but the high torque range is shifted to lower torques.

For the elbow flexion, Figure 71, the distribution of the 0 RPM torques is tri-model; however, it does resemble a normal distribution. The torques of the 5 RPM condition are more normal in appearance; however, the curve is still bi-model. The 25 RPM

TABLE 21. Anthropometric measures

SUB	WGHT	STATURE	ACRHT	SHELB	FAHAN	HLNGTH	FLNGTH
1	74.910	187.3	154.3	38.4	51.2	20.1	28.4
2	81.266	183.2	150.0	38.5	49.8	19.6	27.8
3	77.180	178.4	143.1	39.7	51.0	19.7	27.0
4	69.462	176.0	144.4	37.0	48.4	18.8	26.4
5	79.450	180.4	145.5	39.0	49.0	18.6	26.5
6	83.990	167.9	157.6	38.8	52.1	20.0	27.0
10	66.738	169.7	137.0	36.8	46.4	17.8	25.8
12	59.020	170.8	139.1	35.0	47.0	18.9	25.0
13	70.824	168.9	139.1	35.2	48.2	19.2	26.0
14	88.530	167.0	138.0	35.2	44.2	17.3	24.2
16	72.640	175.0	145.7	37.3	46.6	18.1	25.0
17	81.720	166.8	136.9	35.7	46.6	18.8	25.6
18	78.542	169.6	138.8	34.9	45.5	18.4	24.1
19	68.100	171.6	139.0	37.7	47.5	17.8	26.3
20	86.260	166.3	137.4	33.0	46.5	19.0	24.9
21	66.260	173.1	141.5	36.4	47.8	18.4	26.0
22	108.642	162.7	148.4	38.8	49.5	18.8	27.5
23	88.964	171.5	138.0	33.1	46.4	17.9	26.6
24	83.990	176.0	143.3	34.7	47.1	16.8	27.8
25	63.990	172.0	139.0	34.0	45.6	18.0	25.7

TABLE 21 CONTINUED. Anthropometric measures

SUB	NECK	SHO	CHEST	WAIST	THIGH	CALF	BICEP	FORARM
1	38.5	114.5	100.5	79.5	55.4	34.5	31.0	30.5
2	37.5	116.0	95.0	87.0	59.0	38.0	31.0	29.0
3	38.5	114.3	90.7	78.2	54.0	39.0	34.8	29.7
4	37.5	115.0	98.0	79.0	53.5	35.0	32.0	30.0
5	40.0	121.0	99.0	80.0	55.5	36.5	37.5	30.0
6	40.0	155.0	96.5	86.0	54.5	38.0	32.0	30.0
10	36.0	110.0	90.0	79.0	53.0	38.5	29.0	27.0
12	35.0	104.0	88.0	72.0	49.0	35.0	28.0	27.0
13	37.0	100.1	92.0	83.0	57.0	36.5	33.0	28.0
14	38.0	115.0	98.0	82.0	57.0	36.0	33.5	31.0
16	36.0	117.0	96.5	86.5	53.0	35.5	32.0	28.0
17	40.0	122.5	104.5	91.0	60.5	39.5	36.0	33.0
18	40.5	115.4	100.0	93.2	55.0	38.5	35.0	30.1
19	39.5	115.0	93.0	82.0	55.0	34.5	30.0	27.0
20	36.5	114.5	92.0	73.5	50.5	37.0	33.5	28.0
21	40.0	124.0	104.0	92.0	65.0	41.5	34.5	30.0
22	41.2	132.3	113.4	14.9	66.6	42.3	36.3	33.0
23	39.5	120.0	100.3	1.2	60.1	42.7	33.5	29.1
24	41.5	120.0	101.4	87.8	59.0	42.2	44.6	31.0
25	40.3	121.6	106.9	94.8	58.5	38.7	34.1	30.3

TABLE 22. Descriptive statistics for anthropometric data

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
WGHT	20	79.5	10.6	59.0	108.6
STATURE	20	174.7	6.7	166.3	187.9
ACRHT	20	142.8	5.9	136.9	157.6
SHELB	20	36.5	2.0	33.0	39.7
FAHAN	20	47.8	2.1	44.2	52.1
HLNGTH	20	18.7	0.8	17.3	20.1
FLNGTH	20	26.2	1.2	24.1	28.4
NECK	20	38.7	1.9	35.0	41.9
SHO	20	118.4	11.0	100.1	155.0
CHEST	20	98.0	6.3	88.0	113.4
WAIST	20	76.1	24.2	1.2	94.8
THIGH	20	56.6	4.4	49.0	66.6
CALF	20	38.0	2.6	34.5	42.7
BICEP	20	33.6	3.6	28.0	44.6
FORARM	20	29.6	1.7	27.0	33.0

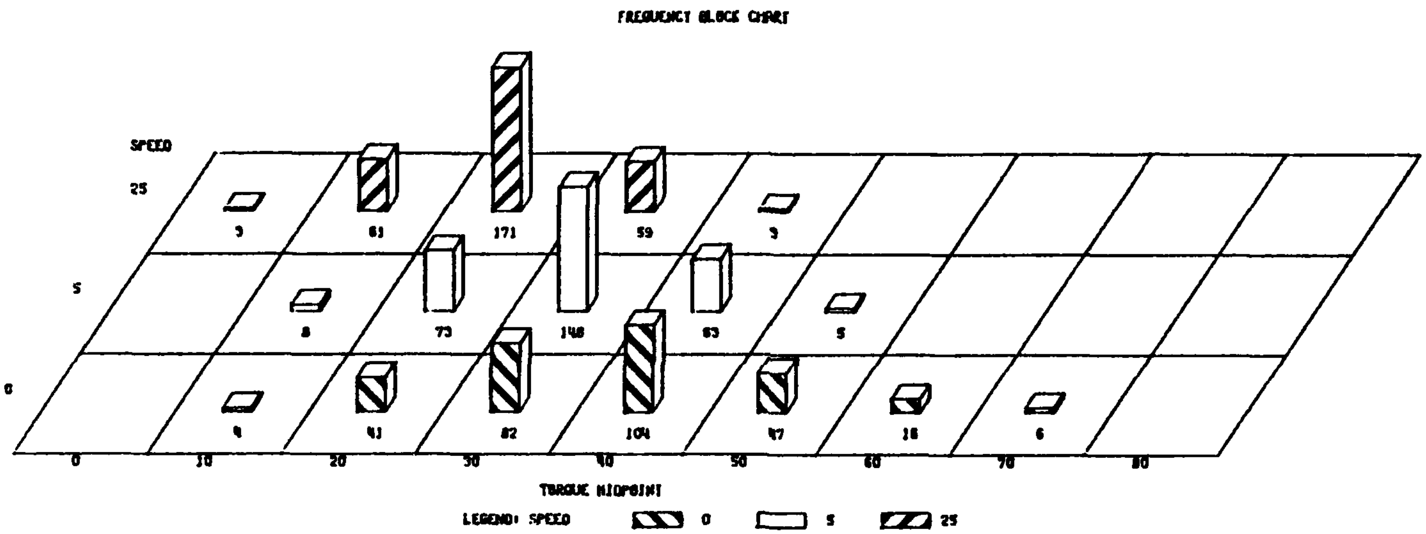

FIGURE 69 FREQUENCY COUNTS OF TORQUE BY SPEED
FOR THE ABD AT 0 ROTATION

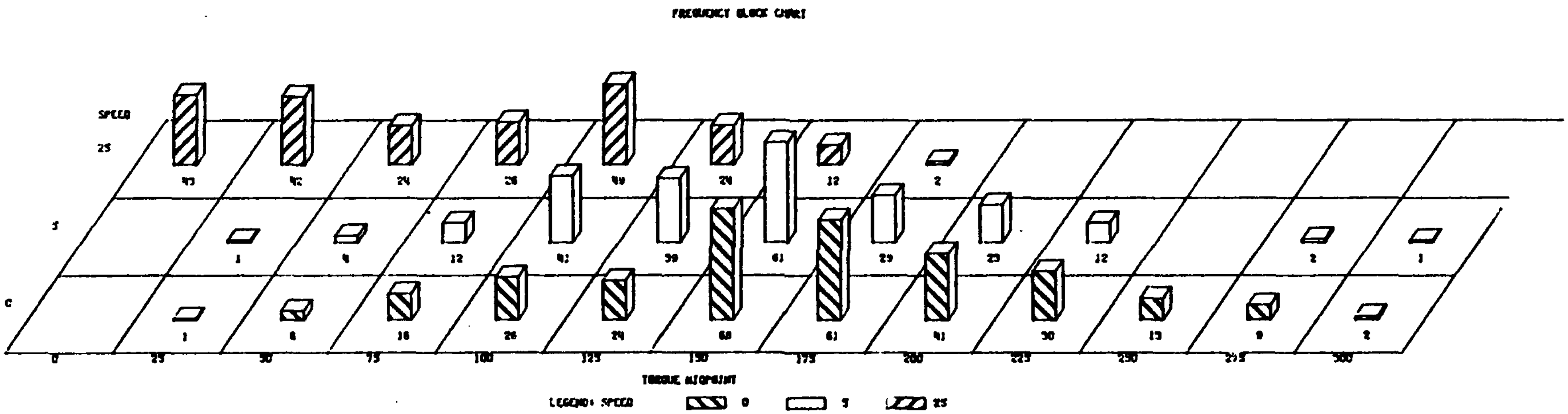

FIGURE 70 FREQUENCY COUNTS OF TORQUE BY SPEED
FOR THE BAC AT 0 ROTATION

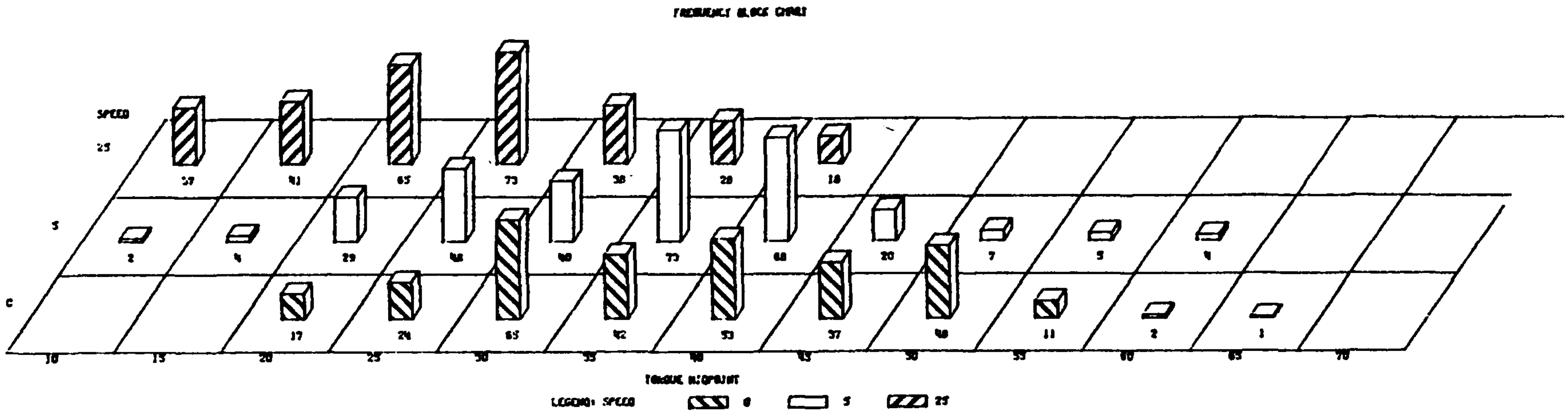

FIGURE 71 FREQUENCY COUNTS OF TORQUE BY SPEED
FOR THE ELB AT 0 ROTATION

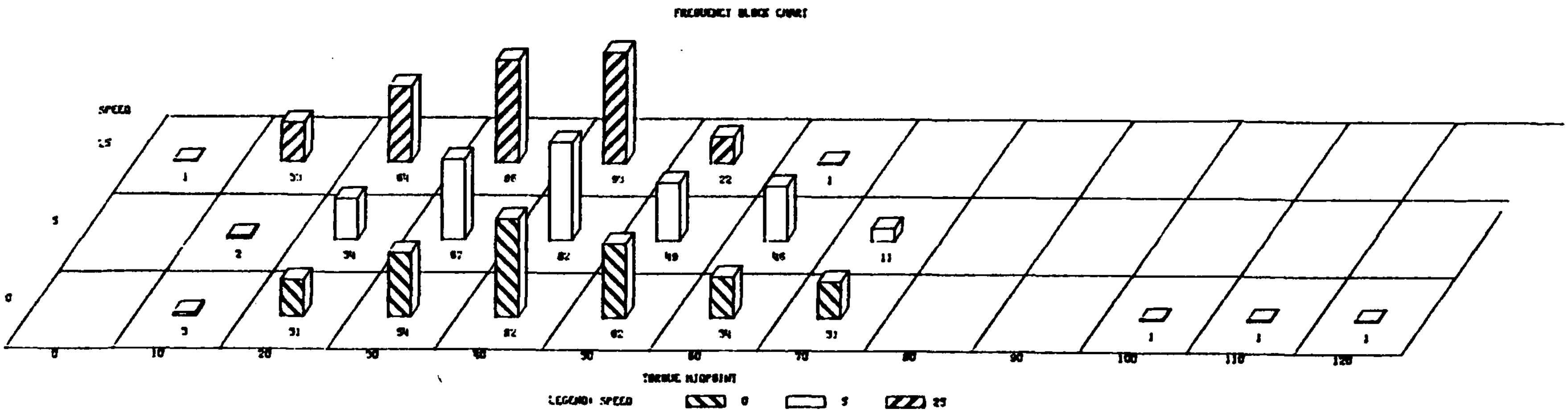

FIGURE 72 FREQUENCY COUNTS OF TORQUE BY SPEED FOR THE HFE AT 0 ROTATION

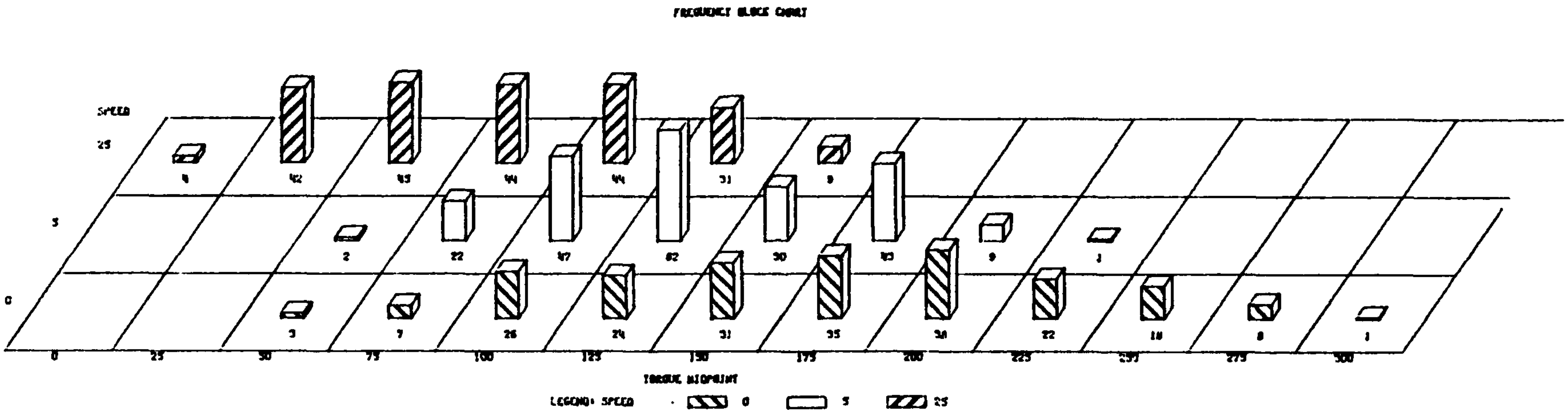

FIGURE 73 FREQUENCY COUNTS OF TORQUE BY SPEED FOR THE HIP AT 0 ROTATION

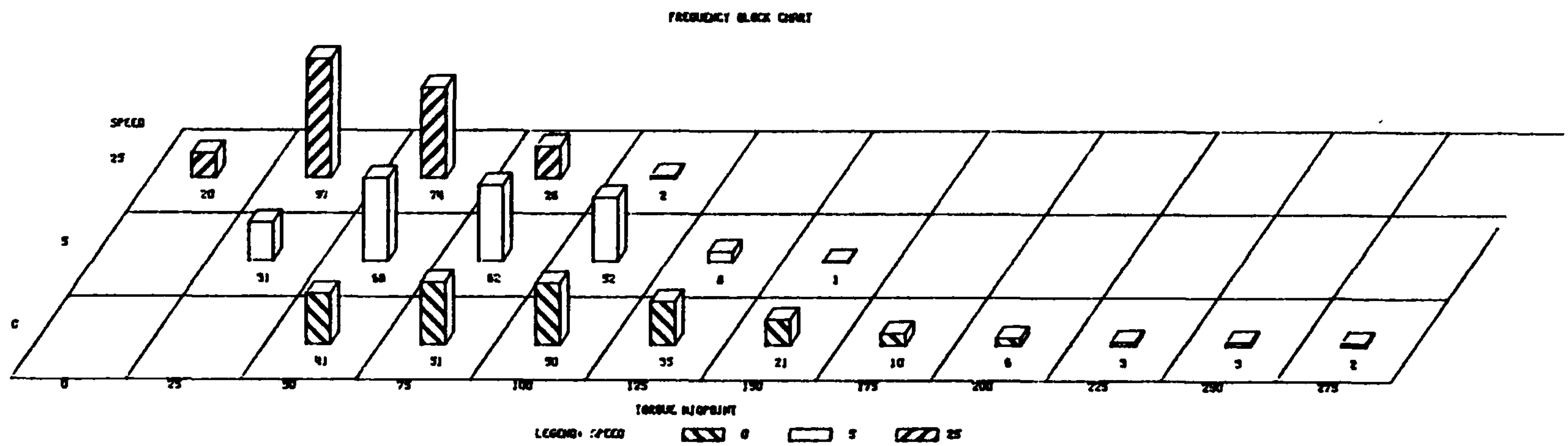

FIGURE 74 FREQUENCY COUNTS OF TORQUE BY SPEED FOR THE KNE AT 0 ROTATION

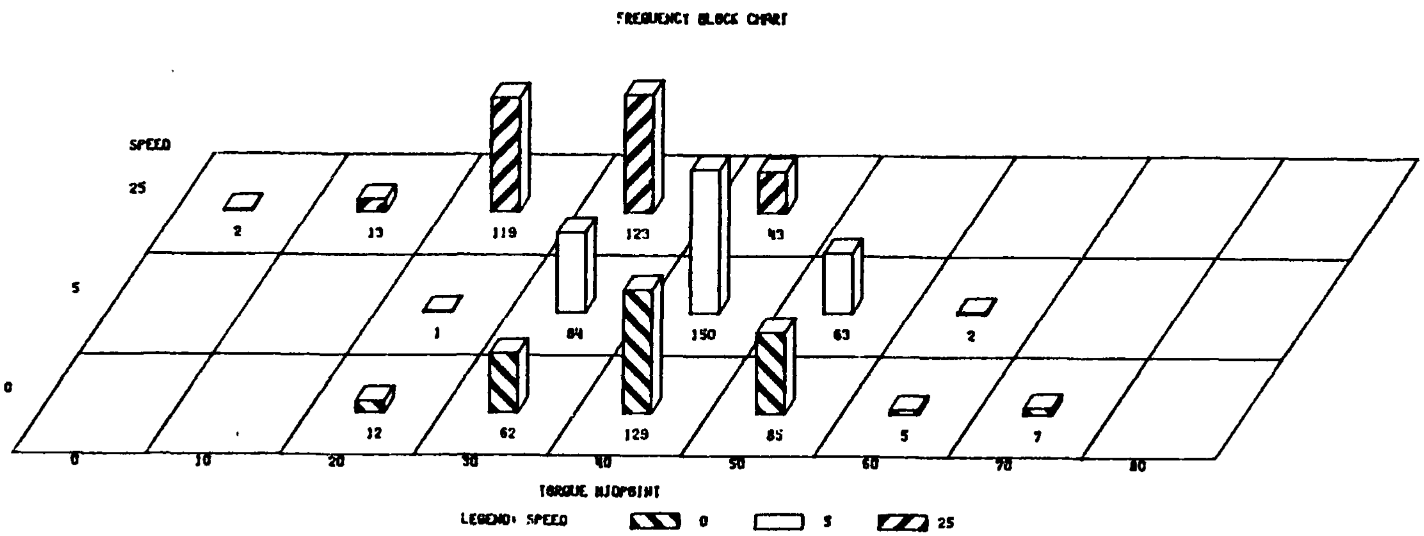

FIGURE 75 FREQUENCY COUNTS OF TORQUE BY SPEED FOR THE VFE AT 0 ROTATION

condition produced data having the most normal appearance of the three sets although the low torques seem to be abnormally inflated. Again the torques seem to decrease on the whole as the speed increases.

The distribution for the horizontal flexion is presented in Figure 72. The data in all conditions appear to be normally distributed. There are three outlyers for the 0 RPM condition making it appear to be a skewed normal distribution. The torques for the three speeds show essentially no real shift or a very slight shift toward lower torques as speed increases.

Like the back extension the hip extension, Figure 73, shows essentially normally distributed torques for the 0 and 5 RPM conditions with no real pattern for the distribution of torques at 25 RPM. The torques do tend to shift to lower values as the speed variable was shifted to higher RPM's.

The torque distribution for the knee extension, Figure 74, is highly skewed while the distributions for the 5 and 25 RPM conditions are very nearly normal in shape. In general, the torques tend to shift to smaller values as the speed is shifted to higher values.

The torques in Figure 75 for the vertical flexion are normally distributed in appearance. There seems to be no shift in torque values as the RPM are increased from 0 to 5 RPM while there is a shift from 5 RPM to 25 RPM.

<u>Goodness of Fit Test of Torque Distributions</u>

Tests were conducted only on the data obtained at the 0° rotation. Only this rotation angle was used since no substantial

difference between the rotations was observed in earlier analysis. Also the starting angle having the largest range of motion was used as a second selection criterion. This choice would allow subjects plenty of time to reach their maximum torque thus eliminating the reported effects of starting angle on maximum torque. For the upper extremeties (ELB, ABD, HFE, VFE) the starting angle was 0°, while 90° was the starting angle for the rest of the joints (BAC, HIP, KNE).

The program described by Phillips (1972) was used to test the torque distribution against the normal distribution. Three statistical tests were used. The Kolmogorow-Smirnov with the number of cells equal to the number of observations was the first obtained. Next used was the Cramer-Von Mises with the number of cells again set to be equal to the number of observations. Finally the Chi-Square test was used with 15 cells specified. Three tests were used to provide multiple estimates of the match of the data to the normal distribution.

The BAC was the only joint which was found to be normally distributed by the three tests (Table 23). For all three speeds, the Kolmogorov-Smirnov and Chi-Square test both supported the hypothesis of normal distibution while the Cramer-Von Mises rejected the hypothesis.

For three of the joints (ELB, HFE, KNE), the distributions for two of the three speeds combinations were found to be normally distributed. The remaining joints (ABD, VFE, HIP) were found to have normally distributed data for only one of the speed conditions.

Table 23. Goodness of fit tests
of the data for normal distribution

JOINT/SPEED/START ANG	KOLMOGOROV-SMIRNOV	CHI-SQUARE	CRAMER VON MISES
ABD / 0 / 0	.081	4.698	5.106
	<.05	>.05	>.05
ABD / 5 / 0	.072	9.820	12.608
	<.05	>.05	>.05
ABD /25 / 0	.1097	30.35	12.830
	<.05	<.05	>.05
ELB / 0 / 0	.125	15.74	14.517
	<.05	<.05	>.05
ELB / 5 / 0	.139	30.28	12.049
	<.05	<.05	>.05
ELB /25 / 0	.201	28.22	12.977
	>.05	<.05	>.05
HFE / 0 / 0	.093	17.57	10.022
	<.05	<.05	>.05
HFE / 5 / 0	.065	7.61	6.455
	<.05	>.05	>.05
HFE /25 / 0	.148	25.07	11.856
	<.05	<.05	>.05
VFE / 0 / 0	.072	8.04	10.187
	<.05	>.05	>.05
VFE / 5 / 0	.1003	8.03	13.367
	<.05	>.05	>.05
VFE /25 / 0	.142	26.39	14.954
	<.05	<.05	>.05
BAC / 0 /90	.075	11.98	1.432
	<.05	<.05	>.05
BAC / 5 /90	.092	1.72	1.486
	<.05	<.05	>.05
BAC /25 /90	.874	9.51	1.705
	<.05	<.05	>.05
HIP / 0 /90	.113	10.33	.735
	<.05	<.05	>.05
HIP / 5 /90	.118	18.65	1.598
	<.05	>.05	>.05
HIP /25 /90	.0898	21.88	1.580
	<.05	>.05	>.05
KNE / 0 /90	.125	6.6	1.956
	<.05	<.05	>.05
KNE / 5 /90	.064	14.78	3.314
	<.05	>.05	>.05
KNE /25 /90	.061	11.48	4.042
	<.05	<.05	>.05

Looking at the speed conditions separately, five joints (ELB, HFE, BAC, HIP, KNE) were found to have normally distributed data at the zero speed or static condition. Also the high speed condition was found to be normally distributed at five joints (ABD, HFE, VFE, BAC, KNE). Only two joints (ELB, and BAC) were determined statistically to be normally distibuted as the slow speed condition of 5 RPM.

Given the results obtained for the testing of the data distributions, no real pattern clearly emerges. Roughly 50% of the distributions were found to be normal. The static and high speed conditions accounted for 85% of the normally distributed data sets.

Accommodated Percentage Model

This model generates data for a set of psuedo-subjects. The data consist of a vector of scores for each of the variables specified for the model. This vector is then tested one component at a time against a pair of cutoff criterion. When the data for a pseudo-subject satisfies all criterion, that psuedo subject is tallied as being accomodated by the task conditions represented by the cutoff criterion.

The pseudo-subjects are generated as normal variate data by a subroutine from the International Math and Statistics Library (IMSL). Using the correlation matrix for the data on actual subjects as a covariance matrix, the (IMSL) subroutine produces a random normal variate and stores the data in an array. Data for any number of psuedo-subjects can be generated by this IMSL subroutine.

The subroutine requires the input of the correlation matrix, the number of variables to be included in the output vector for each pseudo-subject, and the number of psuedo subjects vectors to be generated. A vector array of length equal to the number of pseudo subjects to be generated is output from the subroutine.

The vector for each psuedo-subject is tested one member a time against the high and low cutoff for that member. Failing to meet one cutoff eliminates that psuedo-subject from the accomodation sum. Once all psuedo-subject vectors have been tested, the percentage of these psuedo-subjects accomodated is calculated. This percentage is the model output.

Appendix 3 contains the FORTRAN Program which represents the model. Included with the model are the input parameters, the number of variables, the desired number of psuedo-subjects to be generated, and the high and low cutoff values for the variables. The high and low cutoff values are given in standard deviation units since the values of vector members are normal deviate in nature. The correlation matrix used for the model run is also present. Values for the matrix were taken from the larger matrix found in Table 15. The variables used were: ELB/0, VFE/0, BACK/0, and KNE/0. The last line gives the percent of the psuedo-subject sample accomodated by the criterion specified.

Conclusions

Analysis of the data collected in this study shows that the torque available across a human joint is indirectly proportional to the speed of movement around that joint. Hence if designing a task in which the time available for a movement is small, the

load to be moved should also be small. Heavier loads will require more time to be moved.

In addition, the point in the limb's total range of motion at which the motion starts is a factor. Starting close to the beginning of the limb's range of motion allows a higher peak torque to be developed. Conversely, a motion starting from a point which allows the use of only a small part of the range motion will produce a much smaller peak torque.

Motions in planes deviating slightly from the sagittal plane appear to have negligible effect on the strength which can be brought to bear. Such a finding simply means that workers do not nessarily need to turn the whole body to line up a load in sagittal plane before it can be lifted. However, this applies to loads to be lifted with the arms only. The data in this study are not sufficient to make any declarations about loads in which the major effort is with the legs and back. Extension of the leg at the hip did show some effect of rotation away from the sagittal plane suggesting that the lifting of heavier loads may require the turning of the body to align the plane of lifting motion with the sagittal plane of the body.

Correlations of the static measures with dynamic measure were not high. Such a finding suggests that determination of dynamic strength capabilities from static strength measures is not a recommended practice. In addition, the slower speeds of motion did not correlate well with higher speeds suggesting that the available strengths must be determined at the same speed of motion as that required by the task. However, more research

needs to be done in this area before very definitive statements can be made.

Although data collection in this study was fairly extensive, time constraints did not permit as close a look at some variables as is needed to be more definitive regarding dynamic strength. Only three speeds of motion were examined in this study; static or 0 RPM, 5 RPM, and 25 RPM. Data collection using 5 RPM speed increments would give a finer look at the relationship of torque and speed.

Arbitrary ranges of motion were used in this study; 120° for ELB, HFE, VFE, and ABD, and 90° for BAC, HIP, and KNE. While many subjects had difficulty reaching the 90° position for the BAC, most subjects were able to go far beyond the 120° limit for the shoulder motions. Future work looking at torques throughout the whole range of motion are needed to enable a more complete picture of the torques available at the extreme range of motion.

To complete the atlas of strengths, data should be collected in opposing directions to those used here as well, ie. extension at the elbow as well as flexion. The choices made in this study were limited to those most closely involved in the lifting of a box. Other work tasks would obviously have different motion requirements.

The effect of starting position also needs further examination. In this study, the effect of the starting angle was confounded by the time required to "catch" the Cybex dynamometer before torques could be measured. A system without this lag needs to be used or a means of compensating for the confounding developed.

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APPENDIX A

Height and Weight Criteria Used in Subject Selection

Height and Weight Criteria Used

in Subject Selection

Weight (kg) \ Height (cm)	148.2–156.8	156.8–160.4	160.4–163.6	163.6–167.2	167.2–178.1
63.73–82.05	0	1/2	1/2	1.5	2.5
59.12–63.73	1/2	1.0	1.0	1.0	1.5
55.5–59.12	1/2	1.0	2.0	1.0	1/2
51.41–55.5	1.5	1.0	1.0	1.0	1/2
42.36–51.41	2.5	1.5	1/2	1/2	0

Height (cm)

APPENDIX B

Subject Health Screening Form

PERSONAL DATA AND CONSENT FORM

DATE: ____________________

Texas Tech University
Institute for Biotechnology
Development of an Atlas of Strengths
and Establishment of an Appropriate
Model Structure

TIME: ____________________

SUBJ. NO.: ____________________

NAME: ____________________ AGE: __________
SEX: __________ HEIGHT: __________ WEIGHT: __________

CHECK IF SUSCEPTIBLE TO:

Shortness of Breath: ______ dizzyness: ______ headaches: ______
fatigue: ______ chest: ______ shoulder: ______ arm pain: ______
If so, explain: ____________________

Have you ever had a heart attack? ____ If so, give history: ____________

Are you currently taking any type of medicine? ______ If so, explain: ______

Have you had or do you now have any problem with your blood pressure? ______
If so, explain: ____________________
In the last six months, have you had any type of surgery or serious illness?
______ *If so, explain:* ____________________
In the last six months, have you had any back pain, particularly in the lower back? ______ If so, explain: ____________________
Have you had or do you now have a hernia? ______
Corrective date: ______
Have you ever suffered an injury to your knees, hips, shoulders, or elbows? ______ If so, explain ____________________
Have you ever pulled, strained, or otherwise injured the muscles of the legs, back, arms, or shoulders? __________ If so, explain ____________________

PLEASE READ CAREFULLY

I have truthfully answered the questions to the best of my knowledge, pertaining to my personal data. I hereby give my consent for my participation in the project entitled: Development of an Atlas of Strengths and Establishment of an Appropriate Model Structure. I understand that the person responsible for this project is Dr. M. M. Ayoub (806) 742-3407. He or his authorized representative (806) 742-3543 has explained that these studies are part of a project that has the objective: to develop an atlas of strength for use in improving the design of work stations.

PERSONAL DATA AND CONSENT FORM (Continued)

Dr. M. M. Ayoub or his representative has agreed to answer any inquiries I may have concerning the procedures and has informed me that I may contact the Texas Tech University Institutional Review Board for the Protection of Human Subjects by writing them in care of the Office of Research Services, Texas Tech University, Lubbock, Texas 79409, or by calling (806) 742-3884.

He or his authorized representative has (1) explained the procedures to be followed and identified those which are experimental and (2) described the attendant discomforts and risks; and (3) described the benefits to be expected. During the course of this study, you will be asked to move your limbs or trunk against a static and a dynamic resistance in order to measure your static and dynamic voluntary strength. You will be expected to exert your maximum voluntary strength, the most strength that you can possibly give, on all the tests. To measure your static strength, you will be asked to try to move a fixed object that is connected to a measurement device. To measure your dynamic strength you will be asked to move a bar exerting your maximum strength while moving it. This will be done for three different speeds of movement. While there will be no conditioning training, enough practice will be provided to ensure that you are familiar with the task and motions required to obtain reliable data. The risks have been explained to me as possible sore muscles, muscle strain, headaches, hernia, dizziness and fatigue. There are also possible changes such as abnormalities of blood pressure or heart rate, or ineffective "heart function," and in rare instances "heart attacks," or "cardiac arrest," strokes, or pulmonary embolism.

If this research project causes any physical injury to you, treatment is not necessarily available at Texas Tech University or at the Student Health Center, or any program of insurance applicable to the institution and its personnel. Financial compensation must be provided through your own insurance program. Further information about these matters may be obtained from Dr. J. Knox Jones, Jr., Vice President for Research and Graduate Studies, (806) 742-2152, Room 118 Administration Building, Texas Tech University, Lubbock, Texas 79409.

I understand that I will not derive any therapeutic treatment from participation in this study. I understand that I may discontinue my participation in the study at any time I choose without prejudice.

I understand that all data will be kept confidential and that my name will not be used in any reports, written or unwritten.

SIGNATURE OF SUBJECT:______________________________ DATE:____________

Signature of Project Director
or his authorized representative:______________________________

Signature of Witness to Oral Presentation:______________________________

APPENDIX C

Listing of the Accommodated Percentage Model Program

THE MODEL

```
C SET UP THE IMSL SUBROUTINE
      INTEGER                    NR,K,IR,IER
      REAL                       SIGMA(6),RVEC(2000,3),WKVEC(3),XH,(3),XL(3)
      DOUBLE PRECISION              DSEED
      DSEED        =       466364003.D0
      NR           =       2000
      K            =       3
      L  = ( K * (K + 1) ) / 2
      IR           =       2000
      WKVEC(1)     =       0.0
C READ IN THE CORR MATRIX
      READ(5,5) (SIGMA(I),I=1,L)
    5 FORMAT (10F8,5)
C NOW CALL UP THE IMSL SUBROUTINE
      CALL GGNSM (DSEED,NR,K,SIGMA,IR,RVEC,WKVEC,IER)
C SET THE UPPER AND LOWER CUTOFF LIMITS FOR EACH VARIABLE
C VAR 1 = ELBO
C VAR 2 = BACO
C VAR 3 = KNEO
      XH(1)  = 2.
      XL(1)  = -2.
      XH(2)  = 2.
      XL(2)  = -.2
      XH(3)  = 2.
      XL(3)  = =2.
C TEST EACH PSUEDO SUBJECT ON EACH VARIABLE, COUNT THOSE THAT PASS ALL
      TOT=0.0
      DO  20 I = 1,NR
      DO  25 JVAR = 1,K
      IF (RVEC(I,JVAR)GT.XH(JVAR)) GO TO 20
      IF (RVEC(I,JVAR)LT.XL(JVAR)) GO TO 20
   25 CONTINUE
      TOT=TOT+1.
   20 CONTINUE
      ANR = NR
      EXC = ( TOT /ANR ) * 100
C OUTPUT THE NUMBER OF SUBJECTS ACCEPTABLE AND THE PERCENT
      WRITE (6,8) TOT,EXC
    8 FORMAT(' TOTAL PASSED =',F9.4' MODEL SCCOMODATES ',F10.6,' %')
      STOP
      END
```

THE OUTPUT

```
TOTAL PASSED + 1052.0000          MODEL ACCOMODATES 52.599991 %
```

APPENDIX D

Selected Abstracts of the Literature

STUDY: Andersson, G., Ortengren, R. and Nachemson, A. Quantitative studies of the load on the back in different working-postures. Scand. J. Rehabil. Med. (SE); 1978, 10(16), 173-181.

KEYWORDS: Low back pain, back load, intra-abdominal pressure, disc pressure.

METHODS: The purpose of this study was to obtain knowledge about the magnitude of low back stress under standardized conditions of loading, to evaluate and compare different methods to measure these stresses. Studies of the myoelectric activity were performed on groups of either ten or fifteen subjects. Simultaneous measurements of the myoelectric back muscle activity, the intra-discal pressure, and the intra-abdominal pressure were performed on four subjects.

RESULTS: When the subjects were loaded with 100N in each hand and the angle of forward flexion was increased, there was an increase in intra-discal pressure and in intra-abdominal pressure. The increase in the myoelectric activity was comparatively larger in the thoracic than in the lumbar region. The intra-discal pressure and the intra-abdominal pressure both increased when a) the externally applied load was increased at a thirty degree angle of flexion, and b) the trunk was loaded in lateral flexion as well as in rotation. Consistent differences were found in the levels of myoelectric activity recorded on the lift and right side of the back. During lifting of 100N load from 45 cm above the floor to an upright position, the FRA values at all levels of the back and the disc pressure increased considerably, whereas the intra-abdominal pressure increased only slightly.

SUMMARY: The myoelectric back muscle activities, intra-abdominal pressure and disc pressure all appear to relate to turning moments acting on the spine: the measurement values increase when the trunk moment increases. In the static studies, linear relationships were obtained between each of the parameters and the moment acting on the spine.

CITATIONS: Eleven references.

STUDY: Asfour, S.S. and Ayoub, M.M. Effects of training on manual lifting. Paper presented at the American Hygiene Conference, May, 1980.

KEYWORDS: Training, lifting.

METHODS: Back injuries resulting from manual materials handling are one of the major sources of lost time and compensation claims. One of the possible means of reducing the individual's susceptibility to musculoskeletal injuries is by increasing his/her lifting capability through training.

The paper gives a description of a six week training program that successfully increased the maximal oxygen uptake, static strength, and the lifting capability of ten male student subjects.

The program that the subjects had to undergo, trained them for flexibility, muscle strength (by applying the concept of progressive resistance exercise) muscle endurance (by lifting light loads at high frequency of lift), and cardiovascular endurance (by exercising on a bicycle ergometer).

RESULTS: The results of the training program showed an increase in the maximal oxygen uptake of the subjects. An increase in back, arm, leg, and shoulder static strength also occured. The maximal amount of weight lifted in a compact box, for different heights of lift, increased significantly by training.

SUMMARY: Training was seen to increase the lifting capacity of the subjects.

CITATIONS: 18 references.

STUDY: Ashton, T.E.J. and Singh, M. Relationship between erectores spinae voltage and back-lift strength for isometric, concentric and eccentric contractions. Res. Q. Am. Assoc. Health. Physical Education; 1975, 46(3), 282-286.

KEYWORDS: Isometric strength, concentric strength, eccentric strength.

METHODS: Forty male student volunteers were tested maximally on isometric, concentric, and eccentric back-lift strength with the back 20° from vertical. Each type of contraction, administered in random order, took approximately 3 sec. A hydraulic back dynamometer, cable, load cell, and bar were used for the strength measures; an electrogoniometer measured hip angle and surface EMG's (measured in microvolts) determined degree of activity in the lumbar erectores spinae.

RESULTS: For maximal isometric, concentric, and eccentric back-lift strength, the means were 304.69, 222.94, and 315.31 lb., respectively. ANOVA with repeated test showed that the eccentric and isometric means were significantly greater than the concentric mean. Corresponding mean peak voltage means were 352.21, 389.72 and 384.81 mv. Here, ANOVA with repeated measures did not produce a significant difference between means. Newman-Keuls test demonstrated a significant difference between the concentric voltage per pound force ratio and the ratios of the other two types of contraction.

SUMMARY: ANOVA results yielded significant differences between the mean voltage per pound force ratio for isometric, concentric, and eccentric contractions ($p<.01$). Neuman-Keuls test showed that the maximal concentric strength voltage per pound for force ratio (muscle shortening) was significantly higher than the ratios for both the isometric (no appreciable shortening) and eccentric (some lengthening) cases ($p<0.01$).

CITATIONS: Ten references.

STUDY: Asmussen, E., Hansen, O., and Lammert, O. The relation between isometric and dynamic muscle strength in man. Communications from the Testing and Observation Institute of the Danish National Association for Infantile Paralysis; 1965, 20, 3-12.

KEYWORDS: Isometric muscle strength, dynamic muscle strength.

METHODS: The subjects were 18 men, 18 to 30 years. All 18 underwent concentric and isometric tests, but only 6 of them went through excentric tests also. The experiments called for maximum efforts in every test. When plotted, the results, a smooth curve drawn along the upper limit of the mass of points, was taken to represent the maximum values.

RESULTS: The study demonstrated that if the isometric strength at any position of the arm is set to 100%, the dynamic strength during concentric or excentric contractions of different velocities through the same positions can be expressed relative to the isometric strength. It was found that the dynamic strength during concentric contractions is lower than the isometric strength, and that the strength during excentric contractions surpasses the isometric strength. The higher the velocity, the larger the differences.

SUMMARY: Maximal contractions were performed with the arm-shoulder muscles in a pull on a handle under the following conditions: 1) isometric, 2) concentric, and 3) excentric. It was found that the maximum force was less during concentric contractions, and higher during eccentric contractions than during isometric contractions. The differences increased with increasing velocity of the movement. There was a high degree of correlation ($r = 0.8$) between a person's isometric and dynamic strength, independent of his athletic fitness.

CITATIONS: Seven references.

STUDY: Asmussen, E. and Heeboll-Nielsen, K. Isometric muscle strength of adult men and women. Communications from the Testing and Observation Institute of the Danish National Association for Infantile Paralysis; 1961, 11, 1-44.

KEYWORDS: Isometric muscle strength, age differences, sex differences.

METHODS: As standard subjects about 360 normal men and 250 normal women were measured with respect to 25 different muscle groups. Each test was performed at least 3 times and the best values chosen as the standard. The subjects were grouped together according to age, so that each decennium was represented by 20 to 40 single subjects for each of the two sexes.

RESULTS: Curves representing the actual heights and weights in relation to age of the present study show that the older men and women tend to be somewhat shorter and heavier. On the average, the height of the women is about 92% of that of the men. The average strength value for all women, from all the muscle tests is only 58 to 66% of that of men of corresponding age. Even corrected for body height, women's muscular strength is still only 70 to 80%. The results of the measurements of isometric muscular strength in different ages are given in a series of tables.

SUMMARY: Values for isometric muscle strength, with respect to 25 different muscle groups, of adult men and women in the range of 15 to 65 years for men, and 15 to 55 years for women are presented in a tabular form. The description of muscle tests, is also given.

CITATIONS: Three references.

STUDY: Ayoub, M.M., Bethea, N.J., Bobo, W.M., Burford, C.L., Caddel, D. K., Morrissey, S. and Intaranont, K. Biomechanics of Low Coal. Institute of Biotechnology Texas Tech University; 1979.

KEYWORDS: Anthropometry, sex differences, occupational differences, body strength, energy expenditure.

METHODS: The purpose was to evaluate job demands of low coal mines such that job and work station design could be optimized. Most data was collected at actual mining sites. Tasks analysis, photographs and ventilation data for estimating energy demands of specific tasks were taken in the actual mines. Above ground, anthropometric, strength and physical work capacity data was collected on the miners. 77 males and 25 female miners were used. Therefore, data collections covered characteristics of the miners and selected jobs and the job demand.

RESULTS: Anthropometrically, the low coal miners tend to be larger in the trunk, upper arms and upper legs than the population they were compared to. Their back strength however, was lower than the industiral population. The oxygen uptake of miners was not significantly different than the industrial population. Average energy expenditures of the bolter, miner helpers and timbermen exceeds 5 kcal/min.

SUMMARY: To date this research indicates the job task affects miner's strength in the torso, upper arms and upper legs while back strength is less than that of an industrial population. Some of the jobs selected as demanding proved to be exactly that given that they exceed the average of 5 kcal/min. Further field studies are being performed.

CITATIONS: 32 references.

STUDY: Ayoub, M.M., Bethea, N.J., Deivanayagam, S., Asfour, S.S., Liles, D., Mital, A. and Sherif, M. Determination and modeling of lifting capacity. Institute for Biotechnology Texas Tech University, September, 1978.

KEYWORDS: Sex differences, lifting capacity, age difference, job stress index.

METHODS: The purpose of this study was to generate information which would be useful in designing Manual Materials Handling (MMH) tasks and/or the assignment of workers to said tasks. This would include generating lifting capacity data in regards to maximum acceptable lift, developing prediction models and determining job stress ratio to the physical lifting demand and individual's lifting capacity. The laboratory data collection phase used 73 males and 73 females divided into 3 age groups (20-29, 30-39, 40-49). These subjects were all recruited from industry and had MMH experience. Each subject lifted at the rate of 2, 4, 6, or 8 lifts per minute from 6 different levels, floor to knuckle, floor to shoulder, floor to reach, knuckle to shoulder, knuckle to reach and shoulder to reach. 3 box sizes (12" x 7" x 12", 12" x 7" x 18" and 12" x 7" x 24") were used. Each subject adjusted the load in the boxes to what they considered was their maximum then lifted the box a designated number of times using their own freestyle method of lifting. The field data collection consisted of obtaining historical lifting injury data for different MMH jobs, the work loss due to injury on the job, job demands on a certain number of jobs and develop a job stress index. Twenty-two private companies, which covered 63 jobs, were surveyed.

RESULTS: Male and female differences for lifting capacity were significantly different. As vertical height of the lift increased then lifting capacity decreased. The same held true for the frequency of lift and box size, as they increased, lifting capacity decreased. Age did not affect lifting capacity. Anthropometric data and ismetric strength data are used in the lifting capacity model developed. Eighty-five to 88% of the variance was explained in the lifting capacity models. Work rate was found to be very important when looking at job severity, not just the weight lifted. Additionally as the job severity increases the job injury increases also.

SUMMARY: Sex differences were significant while age was not. Lifting capacity is affected by the vertical height, weight of object, frequency of lift and size of the object. Lifting capacity predictions models were developed using static and anthropometric data. Work rate was found to be very important in determining job severity. The authors contend it is very important to match the worker with the job.

CITATIONS: 138 references.

STUDY: Bender, J.A. and Kaplan, H.M. Determination of success or failure in dynamic (isotonic) movements by isometric methods. The Research Quarterly; 1966, 37(1), 3-8.

KEYWORDS: Dynamic Strength, isometric measurements.

METHODS: The purpose was to determine if performance on isometric tests can predict for performance on dynamic strength. Pull-ups were selected such that the effort could be judged as a success or failure. Subjects were tested on an isometric test, then were tested on pull-ups. Those failing to pull-up were then given exercises to develop pull-up ability. Retesting of these subjects would validate the premise of the study. One hundred twenty-eight males aged 10 to 18 years were used.

RESULTS: The pounds pulled by the subject when divided by his body weight gave a strength index. Successful subjects had a strength index of greater than 1.00, while unsuccessful subjects' index was less than 1.00. The various points in the movement reflected a variability of 19% indicating changes in muscle groups.

SUMMARY: The results reflect the fact that isometric measures can indicate dynamic strength. Additionally, failure at one area of movement does not mean there will be failure in other areas.

CITATIONS: Two references.

STUDY: Berger, R.A. and Henderson, J.M. Relationship of power to static and dynamic strength. The Research Quarterly; 1966, 37(1), 9-13.

KEYWORDS: Static strength, dynamic strength, leg power.

METHODS: The purpose was to see which, static or dynamic strength, is more related to leg power. Sixty-six males aged 18 to 21 years were each given a static and dynamic leg strength test, and a leg power test. Administration of tests were randomized. A dynamometer was used to measure static leg strength. Dynamic strength was obtained by having each subject lift, from a squatting position, the greatest amount of weight they could. Leg power was measured by taking the difference in height from a stationary position and an upward jump.

RESULTS: Leg power and static strength were significant at $p<.01$. Leg power and dynamic strength were significant ($p<.01$) with a correlation of .71.

SUMMARY: The authors contend that the high correlations do not mean static strength could predict dynamic strength or vice-versa, as the correlation between the two was .60 leaving accuracy of prediction is 36 percent. The static and dynamic are equally related to leg power.

CITATIONS: Ten references.

STUDY: Berger, R.A. and Higginbotham, R.B. Prediction of dynamic strength from static strength in hip and knee extension. American Corrective Therapy Journal, 1970, 24, 118-120.

KEYWORDS: Dynamic and static strength, knee extension.

METHODS: The purpose was to determine dynamic and static strength of the knee during knee and hip extension and which static scores predict dynamic strength at angles of 35°, 52°, 90°, 135°, and 170° of the knee. Twenty-four males aged 17 through 24 years, were tested at knee angles 35°, 62°, 90°, 135°, and 170° for static and dynamic strength. A goniometer was used to find knee angle. Test for strength and dynamic strength was taken with the use of a Universal Gym Machine.

RESULTS: Correlations for static and dynamic measures at the angles were .79 at 35°, .96 at 61°, 99 at 89°, and .99 at 167°. Static strength angles at 61°, 89°, 135°, and 167° were the best predictors for dynamic strength. For predicting dynamic strength at 35° the static strength measure at 61° should be used.

SUMMARY: The study indicates significantly high relationship between dynamic and static knee angles. The best predictors of dynamic strength is static strength at the same angles of 61°, 89°, 135°, and 167° with the best dynamic strength angle of 35°is the static strength at 61°.

CITATIONS: Three references.

STUDY: Bigland-Ritchie, B. and Woods, J.J. Integrated EMG and Oxygen uptake during dynamic contraction of human muscles. Journal of Applied Physiology; 1974, 36(4), 475-479.

KEYWORDS: Positive (concentric) work, dynamic EMG/force relationship; motorized ergometer.

METHODS: The authors are attempting to repeat and extend experiments using a bicycle ergometer and to measure oxygen consumption simultaneously. A special ergometer designed by Bigland, Ritchie, Graichen and Words (1973) was used to minimize the contractions of auxillary muscles. The bicycle seat was replaced with an adjustable chair which was mounted behind the bicycle seat. EMG recordings were taken on both legs. One electrode was placed near the patellar tendon and one was placed over the belly of the lateral surface of the quadraceps. Oxygen uptake was measured and oxygen expired was analyzed by a Beckman F3 analyzer.

Three subjects (two male and one female) were used for repeated measures taken on separate days. Forces exerted were randomly selected and ranged from 0-3 kgs for males and 0-2.5 kg for the females, all at 50 rpm. Rest was 15 minutes between each test. Values for EMG tensors and O_2 consumption are given in averages of 1 minute intervals of a complete cycle revolution.

RESULTS: Oxygen consumption and integrated electrical activity are linearly related to force exerted at a correlation of .98 and .92 respectively. Variation in the EMG to force relationship was due to charges in electrode placement each test period. The counts per minute per kg of exerted force varied between the male and female subjects. This is thought to be so because of her smaller size. Female subject also showed leg dominance in each experiment. For each 100 counts min^{-1} increase in muscle fiber activity it is required about .430 liters of additional oxygen supply.

SUMMARY: The relationship of the linear EMG/force contractions can be found everytime if standardized conditions are used. With any measurement of this kind, they warn that any change in velocity will change the linear EMG/force scale. With the use of the oxygen uptake data and the EMG/fiber can give the information the fiber energy expenditure.

CITATIONS: Twenty-three references.

STUDY: Caldwell, L.S. Relative muscle loading and endurance. Journal of Engineering Psychology; 1963, 2, 155-161.

KEYWORDS: Muscle strength, endurance, sex differences, dynamometer.

METHODS: The purpose was to compare endurance abilities of males and females and different loads. An isometric dynamometer handle, strain gages, strain amplifies and a display to indicate to the subject the force they were applying was the equipment used. Eighteen male and 18 females, aged 17 to 21 years, were used. Each was seated in the aparatus and adjusted according to the subjects measurements. Subjects were given practice for strength and endurance tests. Each subject was tested on 6 days each 24 hours apart with endurance loadings of 25, 40, 55, 70, 85 and 100% of their maximum strength.

RESULTS: No sex differences were found. Mean endurance loads were 74.4 sec. for males, and females had 69.8 seconds. The males had twice as much weight of the females. The strength measures did not overlap. The males mean strength was 155 lbs and the female mean strength was 85 lbs.

SUMMARY: As load increased in endurance trials the maximum strength response decreased. There was no sex differences.

CITATIONS: Seven references.

STUDY: Caldwell, L.S. The load-endurance relationship for static manual response. Human Factors; 1964, 6(1), 71-79.

KEYWORDS: Manual pull, endurance, arm.

METHODS: The maximum strength of manual pull was determined for 64 male college students at two arm positions known to yield different mean strengths. Each subject was then required to maintain 50%, 60%, 70% and 80% of his own maximum strength at the two arm positions as long as possible.

RESULTS: The main results of this study were: 1) The mean strength of manual pull was 119.6 lb. at the 80 degree elbow-angle, and 162.0 lb. at the 150 degree angle. At the arm position which yielded the greatest response strength the subjects pulled an average of 103% of their body weight. Two-thirds of the subjects pulled between 86% and 120% of their body weight. 2) An essentially linear relationship was obtained between the relative load and the endurance of the response within the range of relative loads employed. As the load was increased from 50% to 80% of maximum strength mean endurance decreased from 63.3 sec. to 21.4 sec. 3) Force X endurance (the response force multiplied by endurance) was much better at the 150 degree angle than at the 80 degree angle. The influence of arm position, or the control force, on the Force x endurance scores decreased with an increase in load. 4) While stature, weight, and the arm dimensions were related to strength, they were not so clearly related to endurance. At the optimal elbow-angle (150°) there were no statistically significant correlations between the aforementioned body measurements and endurance. Thus, when differences in strength were removed by use of relative loading, endurance was apparently unrelated to body size. 5) With the use of relative loading, individual differences in endurance were unrelated to differences in strength. That is, relative loading apparently compensated for gross differences in strength sufficiently that the residual subject differences may be related to such factors as motivation or physical conditioning.

SUMMARY: Subjects exerted maximum pulls and then held the arm position at 50%, 60%, 70% and 80% of the individuals maximum strength. The subjects greatest pull averaged 103% of their body weight. As the load on subjects was increased, mean endurance decreased in a linear fashion. Endurance appears to be unrelated to body size.

CITATIONS: Eight references.

STUDY: Caldwell, L.S. Measurement of static muscle endurance. Journal of Engineering Psychology; 1964, 3, 16-22.

KEYWORDS: Manual pull, endurance, static strength.

METHODS: Definition: Absolute endurance index, percentage of maximum strength held and relative endurance.

Fifty-six male college undergraduates were employed in this investigation. The subject's maximum strength was measured first and the total duration of the strength trial was 7 seconds. Two types of endurance tests were applied. In one test subject was instructed to pull as hard as possible for a period of 70 seconds in order to measure the absolute endurance index and the percentage of maximum strength held. In the second type of endurance test the time which the subject can maintain one-half of his maximum strength was measured as indicates of his relative endurance.

RESULTS: The main results of the study were: 1) a highly significant correlation ($r = 0.7$, $p<.001$) was obtained between maximum strength and the absolute endurance index, thus indicating a tendency for the stronger subjects to maintain greater force during a sustained contraction; 2) a non-significant correlation was obtained between strength and the mean percentage of strength sustained for 60 seconds. Thus, there was no evidence in support of the statement by Tuttle et. al. that there is a tendency for stronger subjects to experience greater relative decrement in strength during a sustained maximum contraction; 3) a highly significant correlation was obtained between the relative strength assumed at the beginning of the exertion and the decline in relative strength during the period of exertion. Thus, decline in strength was shown to be more closely related to initial effort than to strength, since a non-significant correlation was obtained between strength and decrement in relative strength; 4) the two tests of endurance (relative endurance and absolute endurance index) measured little in common.

SUMMARY: Two methods of measuring endurance were compared. Maximum force and force endurance were found to be correlated significantly. It was not supported that stronger subjects would show a greater decrement in strength than the weaker subjects. The decline of strength was highly correlated to the initial effort rather than being correlated to strength. The two endurance tests proved to measure little in common.

CITATIONS: Eight references.

STUDY: Caldwell, L.S., Chaffin, D.B., Dukes-Dobos, F.N., Kroemer, K.H.E., Laubach, L.L., Snook, S.H., and Wasserman, D.E. A proposed standard procedure for static muscle strength testing. Am. Ind. Hyg. Assoc. Journal; 1974, 35(4), 201-206.

KEYWORDS: Static muscle strength, muscle strength testing.

METHODS: The maximum voluntary strength of handgrip was measured. Three instruction conditions were given; namely, jerk, increase, and hold. A pair of trials separated by a rest period of two minutes was given for each instruction condition. No informal feedback was provided.

RESULTS: The results indicated that the time needed to reach maximum output was depending on the instruction used. For all instruction conditions, the times-to-maximum data were skewed toward the longer times. For jerk, increase, and hold, the values were 1.54, 1.84, and 1.67 respectively. There was little difference in the measure obtained with the various instruction: mean strength was 55.4 kp. for the jerk and increase conditions and 52.4 kp for hold.

SUMMARY: The results of this study emphasize the necessity for explicit instructions to subjects in strength assessment studies, and the importance of reporting in detail all factors which influence the generation of force and its application of a transducer.

CITATIONS: Twenty references.

STUDY: Carlson, B.R. Relationship between isometric and isotonic strength. Archives of Physical Medicine and Rehabilitation; 1970, 51, 176-179.

KEYWORDS: Isotonic, isometric, elbow.

METHODS: The purpose was to examine the isometric and isotonic scores relationship and determine if an isotonic test can predict isometric values. Thirty-six males were subjects. Tests were administered for isometric and isotonic strength of the right elbow. Eight sessions for each measure were given over a six week period.

RESULTS: Reliability between and within testing days was .93 and .94 respectively. Correlations between isotonic and isometric strength ranged from .72 to .90. The raw score values for the tests did differ significantly. Training affected scores of the first and second half of the testing sessions.

SUMMARY: There is a significant relationship between isometric and isotonic measures for the elbow. Absolute values of isometric strength are significantly higher than isotonic strength.

CITATIONS: Fourteen references.

STUDY: Carlson, R.B. and McGraw, L.W. Isometric strength and relative isometric endurance. The Research Quarterly; 1971, 42(3), 244-250.

KEYWORDS: Muscle strength, endurance, right arm flexor, tensiometer.

METHOD: The purpose was to look at the strength and endurance relationship of the right forearm flexor. Thirty-six males, mean age of 20.3 years, were tested over a 6 week period on isometric strength and endurance on 8 different days. Each test was administered twice with strength at 30, 45, 60, and 75%. This included 3 strength and one endurance trial. A bell was used to help warn subjects when they were falling below their percentage and a light alerted them to going above the percentage to be maintained. A tensiometer was used and calibrated.

RESULTS: Test-retest for strength was .94. The endurance was significant on the test-retest at .56, .73, .51 and .48 for 30, 45, 60 and 75% respectively. Negative correlation between strength and endurance were found for each trial, 30% = -.47, 45% = -.46, 60% = -.60 and 75% = -.56. When subjects were divided into 3 equal groups according to strength values a difference in endurance was found with the weakest group performing best.

SUMMARY: A significant difference was found between the strength and endurance capabilities of the subject.

CITATIONS: 17 references.

STUDY: Carlsoo, S. Testing the back and lifting capacity. Scand. J. Rehabil. Med. (SE); 1978, 10(6), 164-168.

KEYWORDS: Lifting capacity, back muscle strength, abdominal muscle strength.

METHODS: The capacity of the deep back musculature was measured with a Darcus Dynamometer. In order to obtain some idea of the strength of the abdominal musculature, the magnitude of an active abdominal wall protrusion was measured, also employing a Darcus Dynamometer. The subjects then performed a series of lifts on a box whose weight was successively increased until the subject reached his/her limit. Electromyographic activity in the erector spinae, rectus abdominis and obliquus abdominal musculature were also recorded in testing of back strength, abdominal muscle strength, and during lifts. Thirty-three men and twenty-three women were utilized.

RESULTS: The results indicated that there is no direct correlation between body weight and the strength of the erector spinae. On the other hand, there was good correlation between back strength and lifting capacity and between back strength and abdominal muscle strength.

SUMMARY: In order to prevent or reduce the incidence of back complaints in people whose daily work calls for lifting, the relationships between lifting capacity and back muscle strength and abdominal muscle strength were studied. A good relationship between back strength and lifting capacity and between back strength and muscle strength were observed.

CITATIONS: None.

STUDY: Chaffin, D. B. Graphical prediction of human strengths for two-handed IV/EVA Tasks, Phase I Report Industrial Engineering Human Performance Group, The University of Michigan, for Biomedical Division - NASA - / MSC under Contract NAS9 - 10973, Ann Arbor, Michigan, April 1971.

KEYWORDS: Lifting, pushing, pulling, strength, gravity space suit, biomechanical model.

METHODS: A biomechanical model was used to predict the two handed strengths for shirt-sleeved activities as a function of hand positions, population size and strength, and gravity conditions. The body was considered to be composed of eight solid links: the feet, lower legs, upper legs, pelvis, trunk, upper arms, lower arms, and hands. The mass of each link was based on the segment-mass/body-mass ratios. The link lengths were established from over-the-body measurements using a reference landmark. Five inputs, variable were systematically varied in this project to determine their effects on two-handed force capabilities. The variables were: a) hand placement (relative to the ankles, b) hand force direction (lift, push, pull), c) gravity (1.g., 0.2g., 0.7g.), d) clothing (shirt sleeved, A > L space suit with backpack), e) size and strength of population.

RESULTS: The following conclusions were observed:
1. The best hand heights for lifting, pushing pulling were at knee height, hip height, and mid-thigh height respectively.
2. The space suit and backpack reduced the average lifting and pulling capability in most cases. The spacesuit and backpack reduced the area in which a person could reach/lift, push, and pull within specific boundries.

SUMMARY: A computerized biomechanical model was used to predict volitional force that a person can produce with both hands while statically and symmetrically loading the body in sagittal plane.

CITATIONS: Twenty-four references.

STUDY: Chaffin, D.B. Human strength capability and low back pain. Journal of Occupational Medicine; 1974, 16(4), 248-254.

KEYWORDS: Back stress, low back pain, job related back injuries.

METHODS: The purpose is to see if there is a correlation between low back pain and an isometric strength test of a person's weight lifting ability. Four hundred eleven men and women in 103 different jobs were kept records on for about one year, in which time there were 25 cases of low back pain. Each job was assessed for physical stress, how much weight was handled on the job and how far the weight was from the balance point before and after the move. This information was then compared to a graph representing men in the work force and their lifting abilities. Using these two a lifting strength rating (LSR) is defined for a job.

$$LSR = \frac{\text{weight lifted}}{\text{predicted lifting strength for each strong man in job lifting position}}$$

Based on the LSR ratings, some jobs were selected for further use in the study. The subjects who worked the selected jobs were to perform two lifting tasks in different postures called the Standardized Position Strength Test (SPS) and the Job Position Strength Test (JPS). The subject lifted the object and once reaching a level of force tolerable on the job, they were asked to hold it for the count of four. This was used with 500 people. During the next year, records were kept on all the subjects as to whether the reported back pain, if it was job related, then it was used in the study. Back pain incidents were computed:

$$\text{Low Back Pain incidence rate for the job} = \frac{\text{\# of low back pains reported}}{\text{\# of man weeks on the job}}$$

RESULTS: Absolute strengths recorded were lower than those found in previous research. The author attributes this to the lack of emotional appeal, explosive efforts and the varying ages of the subjects. A difference in strength abilities between men and women were found. A job strength ratio was formed which indicated whether the job demands had adequate personnel. The jobs were divided into three groups, little or no stress on job, matched worker ability and job stress, and job stress exceeding the workers capabilities. Low back pain incidence was matched to each group. The results reflected a sharp increase in low back pain in the third group.

SUMMARY: The study reflects the potential for use of strength testing as a screening instrument for jobs. Screening would help prevent the number of back injuries suffered each year.

CITATIONS: Twenty-six references.

STUDY: Chaffin, D.B. Ergonomics guide for the assessment of human static strength. Am. Ind. Hyg. Assoc. Journal; 1975, 36(6), 505-511.

KEYWORDS: Static muscle strength, muscle strength testing.

METHODS: This paper has been prepared to assist persons performing strength assessments to better assess human static strength in the future. It is mainly, recommendations for static strength assessment procedure.

RESULTS: The following are the main recommendations given in the paper: a) the voluntary exertion should be maintained for a period of four to six seconds, b) the measurement device should be capable of time averaging the force or torque produced by the person during the steady state, c) the force measuring device should not influence a person's exertion due to it causing localized discomfort at the point where it couples to the body, d) adequate rest periods between repeated exertions are necessary to avoid fatigue, a minimum of 30 seconds should be given if only a few measurements are to be made, e) body position must be specified and controlled, f) subject instructions should be given in writing, and after discussion, a signed statement of understanding should be acquired, g) to enable the comparison and further development of population norms, it is imperative that the reporting of strength values include a good description of the test conditions, h) the following strength statistics should be reported: mean and/or median, mode; standard deviations; skewness or histogram; and minimum and maximum values.

SUMMARY: Recommendations for static strength assessment procedure are given in the paper to assist persons performing strength assessments to better assess human static strength in the future.

CITATIONS: Twenty-one references.

STUDY: Chaffin, D.B., Herrin, G.D., and Keyserling, W.M. Preemployment strength testing. J. Occup. Med. (US); 1978, 20(6), 403-408.

KEYWORDS: Strength testing, low-back injury.

METHODS: Over 900 jobs in six different plants were included in the study. All jobs chosen had at least a 35-pound equivalent weight lifting requirement. During the 18 months follow-up period, 551 people were strength tested for these jobs with all resulting medical and supervision data reported for analysis. Of these people, 446 were men and 105 were women.

RESULTS: Medical incidents were classified by the plant physicians into three groups: 1) back pain, 2) musculoskeletal injuries, and 3) contact injuries such as lacerations, bruises, or abrasions of a traumatic nature. An analysis of these incidents revealed that a worker's likelihood of sustaining a back injury of musculoskeletal illness increases when job lifting requirements approach or exceed the strength capability demonstrated by the individual on an isometric simulation of the job.

SUMMARY: This investigation was conducted to evaluate the practicality and potential effectiveness of preemployment strength testing in reducing the severity of musculoskeletal and back problems in materials handling jobs. The authors concluded that industry should implement specific employee selection and placement programs using a strength performance criterion.

CITATIONS: Ten references.

STUDY: Chapman, A.E. and Belanger, A.Y. Electromyographic methods of evaluating strength training. Electromyographic Clin. of Neurophysiology; 1977, 17(3-4), 265-280.

KEYWORDS: EMG, Hallux Muscle, abduction.

METHODS: The purpose was to see how changes in "Efficiency of Electrical Activity (EEA)", maximal integrated electromyogram (IEMG) and mean square deviation (MSD) of the force/EMG relationship may affect the variability in force. Four males and two females were subjects. Isometric forces of the abduction. Hallux muscle were recorded. Natural foot movement was prevented by adjustable pieces of angle iron. A force transducer recorded the force of abduction which was picked up by attached electrodes to the skin. All subjects were trained to increase the force of the abduction Hallux muscle. Of the training trials, the one with the greatest maximum force was selected from each half at the trials.

RESULTS: All subjects were able to increase force and IEMG during training. EEA increased in five of the eight subjects and MSD decreased in six of the eight. Variability in force is thought to be a combination of EEA and IEMG as the mean r equals .781.

SUMMARY: Great variability for individuals can be accounted for when using IEMG and EEA and 60% can be accounted for when subjects are grouped. Increased force was produced by increasing recruitment or EEA depending on the subject.

CITATIONS: Five references.

STUDY: Christensen, C.S. Relative strength in males and females. Atheletic Training; 1975, 10(4), 189-192.

KEYWORDS: Relative strength, sex differences.

METHODS: Twenty-four male and twenty-four female subjects were utilized to measure both back and leg static extension strength. Total body weight (TBW) and lean body weight (LBW) of each subject were assessed at a second testing session. Each of the back and leg strength tests was administrated twice and the best effort was recorded. At the completion of testing, female and male leg and back strengths were calculated in absolute terms (raw score in pounds) and in relative terms (absolute strength/TBW and absolute strength/LBW).

RESULTS: Males were found to be significantly (.01 level) stronger than females in absolute terms. Leg strength/TBW and leg strength/LBW for males and females were significantly different (.05 level) while the back strength/TBW and back strength/LBW ratios produced no significant differences.

SUMMARY: The present study demonstrated that there is a significant difference between male and female leg extension strength as expressed in both absolute and relative terms, but no difference in back extension strength when expressed as strength per pound of body weight or lean body weight.

CITATIONS: Nine references.

STUDY: Clarke, H.H., Elkins, E.C., Martin, G.M. and Wakim, K.G. Relationship between body position and the application of muscle power to movements of the joints. Archives of Physical Medicine; Feb. 1950, 81-89.

KEYWORDS: Muscle strength, body position, muscle power, muscle length.

METHODS: The purpose of this experiment is to study: 1) the effect of changing body position on muscle strength, and 2) evaluating muscle power throughout range of movements of joints. For the first part of the experiment, sixty four nondisabled college men were tested to compare the amount of muscle strength applied at two different body positions. For the second part, the muscle power exerted throughout the full range of motion for fourteen of the movements of joints was studied.

RESULTS: The results of the first part indicated that body position has a significant effect on muscle strength. The second part showed that the curves representing the muscle power exerted throughout the range of motion of the joints tested can be classified as: 1) ascending curves, that is, increase in strength on motion of joint from angles of 0 to 180 degrees, 2) descending curves, and 3) ascending-descending curves, with greatest strength exhibited in the center of the range.

SUMMARY: These studies provide objective evidence for the statement that, other factors being equal, a muscle exerts its greatest power when it functions at its greatest tension; that the angle at which the muscle pulls is of importance but probably is not of as great importance as the tension, that there probably is an optimal position at which each muscle functions best, and that this position may be one in which the tension is optimal (not necessarily maximal) and in which the angle of pull provides for the greatest rotary force.

CITATIONS: Two references.

STUDY: Clarke, R.S.J., Hellon, R.F., and Lind, A.R. The duration of sustained contractions of the human forearm at different muscle temperature. J. Physiology; 1958, 143, 454-473.

KEYWORDS: Sustained contractions, muscle temperature, EMG.

METHODS: Sustained contractions were made on a simple hand-grip dynamometer located in water. Four healthly young men, trained in the use of the dynamometer, acted as subjects. Each immersed his forearm in the water-bath and immediately made two brief (13 sec) maximal contractions: 1/3 of the mean of these contractions became the target tension for the subsequent sustained contractions. The arm remained in the bath throughout each experiment. After 30 minutes of immersion, the first of five successive contractions to fatigue was made. No subject performed more than one experiment in any 24 hr. period. Water-bath temperatures of 2, 10, 14, 18, 26, 34, and 42°C were used in random order. Muscle temperature was measured approximately midway between the skin and the center of the forearm, i.e. about 4 cm in a distal direction into the brachioradialis muscle at the elbow, using a thermocouple of 40 s.w.g. copper-constantan wire.

RESULTS: The mean duration of contractions revealed that the optimum water temperature for sustained contractions was 18°C. Higher or lower water temperatures resulted in a marked reduction in the duration of the contractions. The optimal muscle temperature for all sustained contractions was between 25 and 29°C, measured at a vertical depth of 2 cm from the skin. Immersion of the forearm in water at 18°C for 30 minutes resulted in a muscle temperature of about 27°C. The subjects were able to exert the same or nearly the same tension after 30 minute immersion in water at 18°C or above. In water cooler than this, the maximum tension exerted fell to a value of 40% of the maximum in water at 2°C. The post-exercise hyperaemic response was greater for a given duration of contraction in water at 34 and 42°C than at lower temperatures. The rate of blood flow through the muscle during contractions also increased by a greater amount when the water temperature was higher. Finally, the integrated muscle action potentials showed that at the termination of the contraction there was no difference in electrical activity (EMG) over the muscle when its temperature was 27 or 35°C, when it was reduced to 20°C there was considerably less electrical activity at the end of the contraction.

SUMMARY: It is considered likely that as muscle temperature increases above 27°C, the rate of metabolism increases and results in the earlier accumulation of metabolites so as to cause fatigue. At muscle temperatures below 27°C a proportion of the more superficial muscle fibers do not contract as a result of interference in nervous or neuromuscular transmission due to cooling.

CITATIONS: Thirty three references.

STUDY: Cooper, D.F., Grimby, G., Jones, D.A., and Edwards, R.H.T. Perception of effort in isometric and dynamic muscular contraction. Eur. J. Appl. Physiology; 1979, 41(3), 173-180.

KEYWORDS: Perception, isometric contraction, dynamic contraction.

METHODS: The perception of muscular effort was studied using estimation and production methods in the adductor pollicis and quadriceps. A psychometric scale (percentage magnitude) was used. Static contractions were studied in the adductor pollicis, and both dynamic (isokinetic) and static contractions were studied in quadriceps.

RESULTS: Linear and logarithmic equations were fitted for the perceived effort as a percentage of the maximum in relation to the produced percentage maximal force or torque. The logarithmic exponent was around or above 1.0. No significant difference was found between mean exponent and intercept values for the adductor pollicis and the quadriceps, or when estimated or produced values for the two muscles were compared. There was no difference in the same subjects between the equations for static and dynamic contractions with low angular velocity of the quadriceps.

SUMMARY: The present study demonstrates that, as with dynamic bicycle exercise (Borg, 1970, 1972), there is a high correlation between perceived exertion and the produced force. Both linear and logarithmic equations could describe the results with a high correlation coefficient. The logarithmic exponent, which was around unity, indicated that the perception of effort for a certain increase in force is the same at low and high forces.

CITATIONS: Twelve references.

STUDY: Corlett, E.N. and Bishop, R.P. Foot pedal forces for seated operators. Ergonomics; 1975, 18(6), 687-692.

KEYWORDS: Foot pedal, isometric.

METHODS: Maximum isometric force produced by a subject was measured when applied to a horizontal foot pedal. This information was used in a design for foot controls to be used in industrial settings, specifically here, spot welders. A horizontal foot pedal was located between two foot rests. The pedal contained a load meter used to register the force exerted on the pedal. The meter was hand reset each trial. An adjustable seat with backrest was used. Twenty males and females, ages 22 to 60 years old, were selected as representative of industrial workers based on height and weight. Four pedal conditions were used; a) leg axis and pedal axis at 90°, b) adjusted seat height for the fifth maximum percentile, c) adjusting seat height for the fifth minimum percentile and d) the seat located such that the pedal was 10 cm. in front of the operator's knee. Both legs were used to obtain data in each of the four conditions.

RESULTS: No significance in leg strength for the four conditions was found. Condition B did result in greated strength measurements than did condition C. Males significantly exerted more strength than females.

SUMMARY: Condition B, although the most favorable, is only the most favorable of the four conditions used. The authors feel the advantage of this position lies in the maximum forces generated with less fatigue than other positions. The authors remind the reader not to make forces greater than those exerted by the weakest user.

CITATIONS: Eight references.

STUDY: Crosby, P.A. Use of surface electromyogram as a measure of dynamic force in human limb muscles. Med. and Biol. Eng. and Comput.; 1978, 16, 519-524.

KEYWORDS: Convolution, dynamic force, electromyogram, muscle.

METHODS: Digital convolution of the input signal and the direct convolution of the impulse response is used as an alternative to using analogue computation. Convolution is defined by equation. The subject lay with his elbow flexed at 90 degrees and wrist immobilized. He was attached to a rod on a force transducer. Electrodes were attached over and parallel to the linea maxima of the medial head of the triceps. Another electrode was placed above the olecranon of the ulna. Where the subject pressed against the force transducer, the signals were recorded as a ten bit digital signal and stored.

RESULTS: Convoluted E.M.G. was fit to the force record in a linear regression. The fit was a good one and was consistently found using thirteen different subjects.

SUMMARY: The author found that in order to use a rectified filter surface E.M.G., the frequencies must be limited to low limits, maximum being about 30 Hz. The rectification allows bi- or tri-phasic impulses (due to several electrodes) to be grouped into a menophasic pulse. The author has made no specific statements regarding gain or offset constants, although there was a correlation between connoluted E.M.G. and mechanical force.

CITATIONS: Twenty-six references.

STUDY: Crowninshield, R.D. Use of optimization techniques to predict muscle forces. Transactions of the ASME; 1978, 100(2), 88-92.

KEYWORDS: EMG, elbow, joint, muscle force.

METHODS: The purpose was to attempt to correlate EMG with predicted muscle activity. Models were developed which included equality and inequality constraints, which worked with muscle stress to predict force in the muscles. For the elbow a planar model was developed which involved the origins and insertions of three muscles. The predicted muscle forces were compared to EMG activity.

RESULTS: The model which produced an elbow flexion moment resulted in a linear relationship when compared to the EMG produced.

SUMMARY: The authors work indicates a good relationship between the predictive models and the real muscle force. However, the author does warn the models may predict higher force than actually occurs because of the movement in the arm causing changes in magnitude. The models correlate with the muscle force quite well.

CITATIONS: Eleven references.

STUDY: Currier, D.P. Maximal isometric tension of the elbow extensors at varied positions: Part 1. Assessment by cable tensiometer. Phys, Ther.; 1972, 52(10), 1043-1049.

KEYWORDS: Maximal isometric contraction, elbow extensors, cable tensiometer.

METHODS: The tension of the elbow extensors of the dominant arm of fourty-one normal male subjects was measured on two different occassions by cable tensiometer during maximal isometric contractions. The elbow positions were varied randomly between 60, 90 and 120 degrees from full extension. Each isometric contraction was maintained by the subject for periods of two to five seconds. A minimum of fifteen seconds was allowed to transpire between contractions. A total of twelve contractions was required of every subject during each test session. Each subject was invited to return to a retest session one week following the initial test session.

RESULTS: The post hoc test revealed significant differences between the 60, 90, and 120 degree positions. The mean of the 60 degree position was lowest [35.8 lb (16.2 kg), S.D. = 7.91 (3.6 kg)], while the 90 degree position [mean = 48.8 lb (22.1 kg), S.D. = 14.83 lb (6.7 kg)] was the greatest computed among the three different angles. The reliability coefficients (test-retest) for the cable tensiometer method were .775, .749, and .723 for the 120, 90, and 60 degree positions, respectively.

SUMMARY: The data analysis of this study revealed that varying the elbow position altered the tension of the muscles. The muscle tension recorded at the 60 degree position was less than that recorded at the 90 and 120 degree elbow position, and the tension at 90 degrees was greater than at 120 degrees. The test-retest correlation coefficients ranged from .723 to .775 for the cable tensiometer method.

CITATIONS: Twenty-six references.

STUDY: Currier, D.P. Maximal isometric tension of the elbow extensors at varied positions: Part 2. Assessment of extensor components by quantitative electromyography. Physical Therapy; 1972, 52(12), 1265-1276.

KEYWORDS: Maximal isometric contractions, elbow extensors, electromyography.

METHODS: An electromyography analysis was performed on the three heads of the right triceps brachii and anconeus muscles of 41 male subjects while performing maximal isometric contractions at 60, 90, and 120 degrees from full elbow extension. All subjects were tested twice with a one-week interval between tests.

RESULTS: The data analysis revealed that varying the elbow position altered both the electrical activity and tension of the muscles. The 60° elbow position resulted in less electrical activity than the 90° and 120° positions while the 90° and 120° positions did not differ significantly from each other. The test-re-test correlation coefficient ranged from .440 to .682 for electrical activity of the different muscle sections and muscle tension evaluated were generally low ranging from -.037 to .453.

SUMMARY: The quantitative electromyographic method did not demonstrate its value as a valid method of assessing maximal muscular force, nor did electrical activity of any individual muscle section seem to be a valid predictor of strength.

CITATIONS: Forty-one references.

STUDY: Currier, D.P. Evaluation of the use of a wedge in quadriceps strengthening. Physical Therapy, August, 1975, 55(8), 870-874.

KEYWORDS: Quadriceps, isometric.

METHODS: This study was developed to help decide whether the use of a wedge for the strengthening of quadriceps was really advantageous. Twenty female subjects were tested on the isometric contraction of the left quadriceps. A goniometer was used for measurements of four knee positions. The subject sat on a N-K table (hip angel 80-100 degrees) during testing. The ankle was anchored with the use of an ankle cuff. Each subject was told to contract the quadriceps muscles for five seconds. Each test was taken at the different angles, with and without the wedge, repeating eight times.

RESULTS: The greatest force was recorded of 60 degree knee position, the least at 0 degrees with and without the wedge. No significant differences were found which would indicate using or not using the wedge.

SUMMARY: The results of knee forces recorded agree with other studies. The use of a wedge or no wedge was not indicated either way. However, the mean forces recorded with the wedge were slightly higher though not significant. The authors feel that the wedge of the size named used could not be advantageous for quadriceps strengthening. This is based on the authors conclusions that the wedge places excessive pressure on the posterior-distal thigh during exercises and thus could actually be painful. Therefore, the use of a wedge remains, still, with the subjective decision of the therapist.

CITATIONS: Thirteen references.

STUDY: Davis, P.R. and Stubbs, D.A. Safe levels of manual forces for young males (this is a three-part series). Applied Ergonomics. Part (1): 1977, 8(3), 141-150; Part (2): 1977, 8(4), 219-228; Part (3): 1978, 9(1), 33-37.

KEYWORDS: Safe load levels for manual work, intra-abdominal pressure, acramonial grip length.

METHODS: A large series of observation on some 200 ft. serving male soldiers was carried out. Subjects were asked to apply measured forces in a variety of positions within the normal reach envelope when standing, sitting and kneeling while their peak intra-abdominal pressures were recorded. The subject's weights, heights and grip lengths were recorded. A computer-based method was used to obtain those points within the reach envelope at which a given manual force gave the same abdominal pressures and thus by interference the same trunk stresses.

RESULTS: The data were used to calculate values for the various positions which would result in maximal peaks in intra-truncal pressures of 90 mm Hg in the weakest soldiers, larger and stronger individuals having smaller values. Where appropriate the 90 mm Hg values were incorporated in contour maps, and in other cases, in simple diagrams.

SUMMARY: Contour maps for 90 mm Hg intra-truncal pressure, were given. These allow a task designer to establish safe limits of applied force for young males when planning work environments in which the operator is required to handle occassional loads, or if the operator needs to handle repeatedly, then 70% of the values can be used. When necessary, two sets of diagrams are presented for a given type of activity, allowing full three-dimensional appreciation of forces within the reach envelope.

CITATIONS: Ten references listed in part (1).

STUDY: Doss, W.S. and Karpovich, P.V. A comparison of concentric, eccentric and isometric strength of elbow flexors. Journal of Applied Physiology; 1965, 20, 351-353.

KEYWORDS: Force during movement, isotonic continuous force, electrogoniometer, force, maximum.

METHODS: The purpose was to compare continuous movement of elbow flexor with isotonic measures at the same angles. A dynamometer and electrogoniometer were used for measurement with the information being recorded on an oscillograph. Elbow angle was measured with an elgen attached to the elbow. Thirty-seven males, aged 19 to 23, were each tested three times with three repeats each time.

RESULTS: The eccentric force at angles 75 to 165° was greater than concentric force. The greatest force for concentric movement was reached at 125° and at 105° for eccentric movement. The correlation between the mean force and mean weight was .90. Comparison of isometric forces significantly corresponded to angles of concentric and eccentric force. Parabolic curves were used for comparison with the data and matched quite well.

SUMMARY: Maximum force obtained during a concentric movement is a good indicator of force determined when lifting weights. The results agree fairly well with previous research.

CITATIONS: Eight references.

STUDY: Duncan, G., Lambie, D.G. and Johnson, R.H. Ventilatory responses to sustained static forearm exercise in man. New Zealand Med. Journal; 1978, 88(618), 169.

KEYWORDS: Static exercise, ventilatory responses.

METHODS: Five healthy subjects were used to study the stimulus for hyperventilation which occurs during sustained static exercise in man and its mode of action.

RESULTS: When the forearm circulation was occluded, end-tidal CO_2, V (increase in minute ventilation), and ventilatory equivalent remained elevated for as long as arterial occlusion was maintained but oxygen consumption returned to normal at the end of exercise. The limb became painful during exercise and remained painful until the cuff was deflated. In one patient with a Brown-Sequard lessions of the spinal cord, increased respiration during exercise was not as marked as with the healthy subjects and pain and post-exercise hyperventilation did not occur when the forearm was occluded.

SUMMARY: The results support the suggestion that proprioceptive sensory pathways from active muscles may be involved in the hyperventilation associated with isometric exercise. They indicate however that a substantial proportion of the respiratory response is probably due to chemical factors stimulating pain receptors within exercising muscle.

CITATIONS: None.

STUDY: Edwards, R.H.T. and Hyde, S. Methods of measuring muscle strength and fatigue. Physiotherapy; 1977, 63(2), 51-55.

KEYWORDS: Muscle strength tests, male and female differences.

METHODS: Two methods of measuring muscle strength were used. First, a myometer was used as a simple hand-held instrument which would register the peak force applied by the examiner in resisting contraction of a muscle group in the course of a conventional clinical neuromuscular examination. Second, the quadriceps force was measured with a strain gauge while the subject was seated in a specially designed chair.

RESULTS: The range of usefulness of the myometer was limited largely by the strength of the examiner in resisting the contractions of the patient's muscles. For this reason the myometer was not suitable for measuring minor degrees of weakness in adults. It can, however, be used to measure strength in normal children and children with muscle diseases. By using the strain gauge, it was found that an adult's predicted normal maximum voluntary contraction (MVC) of quadriceps (in kg force) is equal to 75% of his body weight (in Kg.). No significant difference between males and females has been found in the population studied.

SUMMARY: There are no quantitative methods for measuring muscle function in clinical use today for the diagnosis and management of patients complaining of weakness or fatigue. The systematic and intelligent use of appropriate muscle function tests can be expected to help in the design of rehabilitation programs and evaluation of alternative forms of pharmacological and physical treatments. Two methods for measuring muscle strength were given. The first was found to be inappropriate for adults.

CITATIONS: Fifteen references.

STUDY: Elliott, J. Assessing muscle strength isokinetically. JAMA; 1978, 240(22), 2408-2410.

KEYWORDS: Cybex II, isokinetic, isometrics.

METHODS: A review of the abilities of the Cybex II.

SUMMARY: Cybex II is a machine used to test isokinetic strength. This unit can measure dynamic strength throughout a range of motion. The harder the subject applies force, the instrument will move no faster than its preset velocity. The machine can be used as a diagnostic tool to assess muscle damage which is printed out on a continuous sheet from a electrogoniometer. When there is no previous record of a muscle group performance as an injured subject, the uninjured muscle group performance can be compared to assess injury, time needed for rehabilitation, and type of injury involved. Additionally, the Cybex II may be used for athletic training and as a screening device for weaknesses in an athlete.

CITATIONS: None.

STUDY: Falkel, J. Planter flexor strength testing using the cybex isokinetic dynamometer. Phys. Ther.; 1978, 58(7), 847-850.

KEYWORDS: Planter flexor strength, isokinetic exercise, sex difference, age difference, Cybex isokinetic dynamometer, isometric test.

METHODS: Twenty male subjects and twenty female subjects in each of three age categories, 6 to 8 years, 14 to 16 years, and 23 to 28 years, were tested on the Cybex Isokinetic Dynamometer to obtain normative strength values for the ankle planter flexor muscle group. The muscle strength test was performed using the Lovett method. This method requires the subject to stand barefoot on his preferred extremity, then rise on the ball of this foot up to an angle of at least 45 degrees of ankle planter flexion for ten repetitions.

RESULTS: In the isokinetic test, the 6 to 8 year old girls had a significantly higher mean than did their male counterparts; the 14 to 16 year old boys had a slightly higher mean than did the 14 to 16 year old girls; and the adult men were significantly stronger than the adult women. In the isometric test, the male subjects in all age groups had higher means, and the difference in strength between male and female subjects increased with age. The results of this study showed that age and weight were the only significant variables in determining strength scores.

SUMMARY: By using isokinetic and isometric tests, the standard deviations, means, medians, and ranges were established for male and female subjects in each of three age categories 6 to 8 years, 14 to 16 years, and 23 to 28 years. Results showed that the significant differences in scores were due to weight and age of the subjects, and not due to the sex or height of the individuals.

CITATIONS: Fourteen references.

STUDY: Fay, D.F., Jones, N.B., Porter, N.H. and Wood, R.A. Developments in apparatus for dynamic in vitro testing of human muscle: Part 1. Mechanical design, environment control and stimulation. Medical and Biological Engineering; 1974, 12(5), 647-653.

KEYWORDS: Dynamic in vitro testing of human muscle.

SUMMARY: Some apparatus and instrumentation have been developed for improving the relevance of dynamic test data obtained from human muscle specimens. In the first part of this paper, the background is given and a special clamping and mounting arrangement is described which allows a small specimen to be made ready for test in less than a minute. The second part describes a new timing and sequencing instrument for regulating the electrical and mechanical stimulations applied to the specimen. The mechanical displacements are controlled by a type of servomechanism which can be driven from an f.m. tape recorder.

CITATIONS: Four references.

STUDY: Fisher, B. A Biomechanical Model for the Analysis of Dynamic Activities. M.S.I.E. Thesis; University of Michigan Ann Arbor, Michigan, 1967.

KEYWORDS: Biomechanical model, dynamic activities, strength, stress, lifting.

METHODS: A biomechanical model was developed for symmetric motions performed in the sagittal plane. The model is concerned with non-repetitive, short duration lifting and the stress in the region of the last two lumbar discs. In order to develope the model, the reactive forces and torques on the six articulations of the body (wrist, elbow, shoulder, hip, knee and ankle) were resolved. Next, the spinal considerations were added to the model. The model is an extension of the previous models, and is programmed for the computer. There are two types of input to the model:

(1) The mass and length of the links of the body,
(2) A description of the motion of each link for the activity being analyzed.

The subject data can either be measured directly using the described method or be obtained from the available data. The description of the motion is obtained by photographing a subject with neon lights attached to the point of reference that flashed at a given rate.

RESULTS: The available data from the literature was used to develope a biomechanical model. The model was applied to two types of lifting, a leg lift and a back lift. It was concluded that lifting should be done smoothly and slowly and that the trunk should be kept as erect as possible. It was shown that the stresses on the spine can be compared to the maximum strengths of the components. Based on the strengths of the vertebral end-plates, even lifting a ten pound weight might cause a fracture in persons under fifty. Lifting fifty pounds (which causes a normal force on the S-1 vertebrae of 568 kg) would be very dangerous for anyone over fifty years of age. In regard to subject differences it was demonstrated that the stresses for the particular lift performed were as much as 15% to 20% higher for the average for woman as compared to the average man.

SUMMARY: A biomechanical model was developed for non-repetitive short duration lifting in the sagittal plane. The model inputs were the mass and lengths of the links of the body and the description of their motion. The model was applied to a particular lifting condition and the data were analyzed.

CITATIONS: Forty-two references.

STUDY: Freund, H.J. and Budingen, H.J. The relationship between speed and amplitude of the fastest voluntary contractions of human arm muscles. Experimental Brain Research; 1978, 31(1), 1-12.

KEYWORDS: Voluntary contractions, speed control, synergistic innervation, open-loop movements.

METHODS: The purpose is to study the fastest voluntary contractions with the hand and fore-arm muscles. Six males, aged 24-40 years, were used as subjects. Each subject sat in a chair and was presented with a display to which they were to make isometric contractions or isotonic movements as quickly as possible. Any angle could be used during the achievement of the contraction. Additionally, each subject was on another occasion given a target force or angle to achieve. This required their moving on oscillascope trace onto another. The tension and angle were varied in eight steps and six steps, respectively. A d.c. strain gauge was used to measure tension. The gauge could be used in three positions on the forefinger. Readings from the strain gauge were amplified onto an oscillascope. For the isotonic measures the hand or forefinger were placed in a rigid sleeve and was measured by an angular position transducer, based on the axis of rotation.

RESULTS: The voluntary isometric contractions during the non-target conditions were the fastest at 2.3 kg. In the target condition the rate of rise of tension (RRT) curves were fairly constant. There was no significant difference between target and nontarget contraction times. The target condition revealed a linear relation between the RRT and increasing strength of a contraction. The same was not found for the non target condition. Comparison between three muscles and the RRT force revealed no time difference between them. Three different stages of positional movements were identified. The speed for stages one and three was 40 msec. and stage 2 takes 20 msec. with the RRT being twice as fast. RRT and time of contraction appear to be independent of the exerted force. No significance was found between extension and flexion time. EMG recordings and the duration of contraction were found to take the same amount of time. Antagonistic and agonist muscles were found to be activated simultaneously.

SUMMARY: The study revealed a consistency in the rise time regardless of strength, therefore, it appears speed is controlled by the amplitude dependent regulation of contraction velocity. This consistent rise time also helps to explain the ballistic movement in an open loop system. The action occurs and cannot be corrected or changed as the rise time does not change. Thus, one is the reflection of the other.

CITATIONS: Twenty references.

STUDY: Grasley, C., Ayoub, M.M. and Bethea, N.J. Male-female differences in variables affecting performance. Proceedings of the Human Factors Society, 22nd annual meeting, 1978, 416-420.

KEYWORDS: Male and female differences, anthropometry, biomechanics, physiology.

METHODS: The purpose was to review male and female differences as reflected in the literature. The areas under specific consideration were anthropometry, bmomechanics and physiological differences and how the differences affect occupational performance.

RESULTS: When anthropometry was lookd at the literature reflects fault in design of equipment rather physical capacities. Biomechanical differences between males and females was not found to be as clear cut as the anthropometric measures. Biomechanicaly the females appeared to function at a lower rate of performance than the males. Physiologically the males and females varied greatly. The responses were similar while the physical differences were seen in oxygen uptake, physical conditioning and heat stress.

SUMMARY: The authors stress the need for future research as they state the literature does not give enough ground to base rules on sex alone.

CITATIONS: Thirty-seven references.

STUDY: Haffajee, D, Moritz, U. and Svantesson, G. Isometric knee extension strength as a function of joint angle, muscle length and motor unit activity. Acta Orthop. Scand.; 1972, 43(2), 138-147.

KEYWORDS: Maximum isometric contraction, EMG, knee extensor, angle of flexion.

METHODS: Simultaneous recording of isometric knee extensor torque, integerated electromyogram from quadriceps muscles, and joint angle was performed in 19 healthy subjects (15 females and 4 males). Fifteen subjects were studied at maximum voluntary contraction; 6 performed contractions with constant EMG output.

RESULTS: The individual torque values of 6 subjects tend to coincide at 50 degrees of flexion, where all subjects show a definite maximum. At 10 degrees of flexion, the average torque is reduced to about 50% of maximum value. At constant myoelectrical activity the torque has its maximum at about 40 degrees of flexion. In the nearly extended position and at 90 degrees of flexion the torque is reduced by about 50 percent.

SUMMARY: At maximum voluntary contraction of the quadriceps, the average amplitude of the integrated electromyogram increased as the knee was held in a more flexed position, but the quantitative relationship between different subjects varied considerably. In contrast to the shape of the torque curve, the curves of the integrated EMG show an increase through the whole range of motion tested.

CITATIONS: Nine references.

STUDY: Hatze, H. The complete optimization of a human motion. Mathematical Biosciences; 1976, 28, 99-135.

KEYWORDS: Human movement, modeling.

METHODS: A subject is placed in a restrictive upright position. His pelvis is fixed by a leather belt to a steel frame and his right foot is weighted. The subject is to hit a target with the weighted foot from a relaxed start position. The movement is timed. A mathematical model is developed to predict the optimal performance. The model would then be compared to the living organism.

RESULTS: The trajectories of the model and the human were found to be very close to one another. The controls of the model and human reflect differences where the human exhibits sensitivities of the controls.

SUMMARY: The author has shown that accurate models can be developed to describe human movement and motion.

CITATIONS: 45 references.

STUDY: Heyward, V. Relationship between static muscle strength and endurance: An interpretive review. American Correctional Therapy Journal; 1975, 29(3), 67-72.

KEYWORDS: Static strength and absolute endurance, and muscles.

METHODS: A summary of each type of muscle endurance is discussed. Tables are presented for inter-study comparisons.

Static strength and absolute endurance: The results between static strength and endurance for men has been a negative relationship which may be accounted for by differences in muscle fiber contraction and intramuscular occlusion. There is no data equitable regarding women.

Static strength and static, intermittant endurance: Depending on the conditions, stronger subjects may fatigue faster than low strength subjects. Again, intramuscular tension may occlude intramuscular circulation depending on the subject strength capabilities leaving an imbalance of energy depletion and replenishment.

Static strength and relative endurance: Measurements at different tension levels show low strength subjects to endure longer than high strength subjects, up to 80% tension were the groups appear to perform the same. Occlusion of muscular mass is seen here as a possible cause for the difference between the groups.

SUMMARY: The literature review revealed: 1) the mean force maintained for a period of time is significant between static strength and absolute endurance. 2) Negative correlations between the static strength and endurance have been recorded. 3) For maximal strength measurements at intermittent endurance tasks, stronger subjects exert a smaller force.

CITATIONS: Twenty-seven references.

STUDY: Heyward, V. and McCreary, L. Analysis of static strength and relative endurance of women athletes. Research Quarterly, 1977, 48(4), 703-719.

KEYWORDS: Static maximal strength, endurance time, female subjects.

METHODS: Women athletes (50 subjects), age 18 to 30 years, served as subjects for this study to investigate the relationship between static maximal strength and relative endurance of the grip squeezing muscles. Three maximal grip strength trials with a one minute rest between trials, and one relative endurance test were performed by the subject, while seated, for the preferred hand. For the relative endurance test, each subject sustained a submaximal force representing 30% of her maximal grip strength ($\bar{x}$ of the three strength trials) for a long as possible.

RESULTS: The means and standard deviations for a maximal grip strength (kg) were 39.29 and 5.51 respectively while for endurance time (sec.) were 247.2 and 62.3. The results indicated no relationship between maximal strength and endurance time ($r = .00$). A comparison of the endurance times of women athletes with previously reported scores for college-age males revealed that the mean endurance time for women athletes (247.2 sec.) was significantly greater than that for men (200.3 sec).

SUMMARY: The relationship between maximal strength and endurance time for women athletes was $r = .00$. The results were discussed in light of evidence that suggests possible sex differences in muscle hypertrophy, capillarization of muscle tissue, critical occluding tension level, and intramuscular occlusion.

CITATIONS: Forty-one references.

STUDY: Heyward, V. and McCreary, L. Comparisons of the relative endurance and critical occluding tension levels of men and women. Research Quarterly; 1978, 49(3), 301-307.

KEYWORDS: Sex differences, endurance, maximal voluntary contractions.

METHODS: The purpose of the study was two fold, first, male and female related endurance was compared and the critical occluding tension level (COTL) of males and females during endurance was compared. Eighteen males and 18 females were used. Each subject performed six endurance tests for a 2 x 3 design. Three tension levels (45, 60 and 75% of maximal voluntary contraction) and two arm circulation conditions (artifically occluded or intact) were the six different conditions. A sphygomanometer cuff was used to produce the artificial occlusions.

RESULTS: The analysis revealed occulsions of the forearm did affect endurance of males and females on grip strength. When broken down between the men and women the women were more affected by the occlusion than the males. For women the COTL was 60% of the maximum voluntary contractions. Men did not show differences in the endurance times for either occluded or nonoccluded conditions.

SUMMARY: The authors explain the womens higher (60% MVC) COTL to be due to the less muscle mass found in womens arms. Therefore, it would take greater contractions of the muscle to produce the equivalent occlusion in men (45% MVC). COTL is higher in women than men. Previous research by Heyward (1975) reflected COTL differences between lowered high strength men, therefore the differences in this study were not attributed to sex.

CITATIONS: Twenty-one references.

STUDY: Hight, T.K., Piziali, R.L., and Nagel, D.A. A dynamic nonlinear finite-element model of a human leg. Journal of Biomechanical Engineering - Trans. of ASME; 1979, 101(3), 176-184.

KEYWORDS: Finite-element model.

METHODS: A computer model of the human leg was designed to respond to experimentally measured forces registered at a specifically instrumented ski binding during actual downhill skiing maneuvers, and to predict both leg motion and internal loads and stress levels. In addition, the physical characteristics of sample legs have been measured, including the geometries of the relevant bones and the nonlinear force-displacement relationships of the knee.

RESULTS: Numerical examples are presented which demonstrate the nonlinear capabilities of the model. In addition, a brief example illustrates the ability of the model to respond to a complex loading history measured during a downhill skiing maneuver and to predict cross-sectional stress levels.

SUMMARY: A dynamic, nonlinear finite-element model of human leg has been presented which is capable of representing the three-dimensional motion of a passive leg, including knee nonlinearities, subjected to static or dynamic loading. The model is specifically formulated to permit the calculation of rigid-body motions and elastic deformities, and to facilitate the economic evaluation of bone cross section states of stress.

CITATIONS: Twenty-nine references.

STUDY: Hulten, B.; Thorstensson, A.; Sjodin, B.; and Karlsson, J. Relationship between isometric endurance and fibre types in human leg muscles. Acta Physiol. Scand., 1975, 93(1), 135-138.

KEYWORDS: Isometric contraction, endurance muscle fibre composition.

METHODS: To investigate how fibre composition is related to isometric endurance, 19 subjects were examined at 50% of MVC, and muscle biopsies were obtained for fibre-typing. The experiments were performed in an isometric chair by pressing the feet against an immovable bar whereby activating mainly the thigh muscles.

RESULTS: Individual MVC ranges 195-400 kp (mean 245 kp) and fibre composition 38-69% slow twitch fibre (ST) (mean 54% ST). No relationship was found between MVC and fibre type composition. Endurance time at 50% MVC ranged 56-94 seconds and was related to the individual fibre type composition, demonstrating an increased performance with a higher percentage ST fibres.

SUMMARY: Relationship between isometric endurance performance at 50% MVC and skeletal muscle fibre composition has been elucidated in 19 subjects. This was found to be linear and the equation corresponded to: $Y - 9.35 + 1.093x$; $r = 0.70$ (endurance time expressed in seconds and fibre composition as percent slow twitch fibres (ST) for the vastus lateralis muscle). It is suggested that lactate formed in fast twitch muscle fibres (FT) is released and stored in nonrecruited ST fibres. The ability to sustain isometric tension would then depend on how large the fraction of ST fibres is that can serve as a lactate recipient for lactate producing FT fibres.

CITATIONS: Eleven references.

STUDY: Huston, R.L, Passerello, C.E., Hessel, R.E., and Harlow, M.W. On human body dynamics. Annals of Biomedical Engineering; 1976, 4(1), 25-43.

KEYWORDS: Human body dynamics.

METHODS: In this paper, the foregoing theories and in particular the works on chain systems, were used to develop a general approach and procedure for studying the dynamics of a human-body model.

RESULTS: Techniques and algorithms were presented which efficiently lead to a full set of governing dynamical equations for a 34-degrees-of-freedom model. These equations were developed so that limb motions may be either specified or left free. The unknown moments or displacement were then determined. A simple illustrative example was also given.

SUMMARY: A full set of governing dynamical equations for Hanavan's human body model were developed. The model consists of ellipsoids, elliptical cylinders, and frustrums of elliptical cones. It contained 34 degrees of freedom. The model was considered to be in an arbitrary force field and the limb motions may be either specified or left free. The governing equations then determine the internal limb moments (muscle force), the limb displacements, and the displacement of the model itself in an internal reference frame. An example motion representing the model response to an impulsive force loading was also presented.

CITATIONS: Thirty-two references.

STUDY: Ikai, M. and Steinhaus, A.H. Some factors modifying the expression of human strength. Journal of Applied Physiology; 1961, 16, 157-163.

KEYWORDS: Muscle capacity, forearm flexors.

METHODS: The purpose was to explore what causes and how to change the psychologic limit of human capacity. The forearm flexors were measured with a cable tensiometer and was recorded on the tensiometer dial, then converted to pounds by reference to a calibration curve. The subject performed the movement every time the second hand on a clock passed the one. One group of ten subjects exerted effort every minute for thirty minutes, the performance of the group was averaged to get one curve which decreased over the thirty minutes irregularly. The ten subjects plus 15 more each exerted maximum effort every minute for 35 trials. Occasionally a .22-caliber starter's gun was fired behind the unaware subject at intervals of 2, 4, 6, 8, or 10 seconds before the subject was to exert effort. On the last session, the subject was to shout as loud as possible while exerting the final pull. The original ten subjects were also subjected to hypnosis. Once sufficiently hypnotized the subject was told he could pull with maximum strength for five trials, then become very weak for five trials, then very strong again for five trials and finally return to sleep. When the subject was awakened he was instructed to pull maximally again five times. He was put to sleep again, told he would feel wonderful, awakened and asked to pull five more times. Again, the same ten subjects were tested before and after consumption of 15-30 ml of 95% ethyl alcohol in water. The subject then exerted pulls once every minute for 25 minutes. In another session, the subjects were administered three 10 mg. tablets of amphetamine sulfate orally. After a 25 minute waiting period the subjects performed pulls once a minute for 30 minutes.

RESULTS: When shots were fired behind the subject, there was a significant ($p = .001$) increase of 7.4% in the next pull performance. The average of the shout pulls compared to the average pulls showed a significant ($p = .001$) 12.2% increase in performance. Under hypnosis when strength suggestions were given, performance increased ($p = .01$) an average of 18.3 lb and 15.5 lb. during post hypnotic suggestion. The change in performance while under alcohol and adrenaline was not significant. Amphetamines significantly affected subjects performance 13.5%.

SUMMARY: The results are suppported by other similar research reflecting human strength is affected by psychological inhibitions as can be seen with the hypnotized subjects. The authors feel these findings in agreement with other research, lead them to question the estimates and testing of fitness programs.

CITATIONS: Ten references.

STUDY: Ingemann-Hansen, T. and Halkjaer-Kristensen, J. Force-velocity relationships in the human quadriceps muscles. Scand. J. Rehab. Medicine; 1979, 11(2), 85-89.

KEYWORDS: Isokinetic contractions, knee extensor, muscle fibre composition.

METHODS: Fifteen male soccer players participated in this study to relate force-velocity properties and muscle fibre composition in knee extensors. Muscle tissue was obtained from the lateral portion of the quadriceps femoris muscle by needle biopsies. At least 200 muscle fibres in each section were classified as Type I and Type II. The cross-sectional fibre area was determined by planimetry of 20 fibre of each type. Maximal voluntary knee extensions (torques) at constant angular velocity was measured by means of isokinetic dynamometer.

RESULTS: In the range of motion the angular velocity was constant from 90° to 20° of knee flexion. The angular velocity could be varied from 30 to 360°/s. The average knee angles (SE) at which peak torque occured were 66.6° (1.3) and 43.4° (1.8) at 69 and 310°/s respectively. The peak torque was found to decrease linearly with increasing angular velocity in a semi-logarithmic scale. The present soccer players mobilized 77 MVC at a knee angular velocity of 180°/s.

SUMMARY: An estimate of the peak torque-velocity relationship in an experimental subject was obtained from the slope of the regression line. No correlation was demonstrated between the slope and the fibre composition in the lateral portion of the quadriceps muscle.

CITATIONS: Twenty references.

STUDY: Jackson, A.S. and Frankiewicz, R.J. Factorial expressions of muscular strength. Research Quarterly; 1975, 46(2), 206-217.

KEYWORDS: Legs, arms, static, dynamic, explosive, force, power, work.

METHODS: The purpose was to clarify the factors in human strength by looking at individual differences. Fifty males were administered 16 different tests. The tests were combinations of type of contraction (static, explosive, and dynamic), biomechanical quality (force, power and work), and body segment (arms and legs) resulting in a 3 x 3 x 2 design. A universal gym was used to obtain work measures and photo electric cells were used in some of the tests to obtain the subject's elapsed time.

RESULTS: The four confirmed models were 1) Static-Force-Arms, 2) Static-Force-Legs, 3) Explosive-Power-Arms, and 4) Dynamic-Work-Arms. When height and weight were controlled, their Explosive-Work-Legs and Explosive-Power-Legs were supported tentatively.

SUMMARY: While arm work and force are indicated to be independent constructs which conflicts with other research. An additional 40 subjects were run on the arm tests and results were not significant. The authors feel movement should be considered an important variable in these tests. Leg and arm static forces were seen as independent of one another.

CITATIONS: Thirty-six references.

STUDY: Jensen, R.K. Dynamometer for static and dynamic measurements of rotational movements. The Research Quarterly; 1976, 47(1), 56-61.

KEYWORDS: Static and dynamic, rotation movements, shoulder and forearms.

METHODS: The purpose was a presentation of a dynamometer which measures static and dynamic loads and evaluation of the equipment. The dynamometer made from was a rotary torque actuater where the axle rotation was controlled through pressurized fluid through valves. When the valves were blocked completely, the measure taken was static, when open (depending on how much) the measure was dynamic. Strain gauges measured the bending strain and angular displacement measured by linear variable differential transformer. The signals were amplified recorded on tape, the tape played to an analogue to distal computer for analysis. Arm extension at the shoulder and forearms extension at the elbow was tested for both static and dynamic strength. Forty-two males ages 8-11 years, were allowed two practice sessions three to six weeks before the test. The test was four maximum trials in each angle.

RESULTS: Tests of validity and reliability held. Instrumental accuracy was measured and found to be correct. Weights and scales used were tested and found accurate. Calibration relationships were linear.

SUMMARY: The dynamometer constructed shows potential for further use with static and dynamic measurements. The accuracy and precision of the instrument were high and test vaildity and reliability are adequate.

CITATIONS: Five references.

STUDY: Johnson, J. and Siegel, D. Reliability of an isokinetic movement of the knee extensors. The Research Quarterly; 1978, 49(1), 88-90.

KEYWORDS: Isokinetic movement and knee extensors.

METHOD: To develop a table which could be consulted for procedures to use to obtain reliable measures, the authors used isokinetic movement of the knee extensors. Forty females, ages 17-50, were used to take readings of the knee at 90°. A Cybex II was used set at 180°/sec. Force was recorded by the Cybex II records in foot pounds. The peak of each trial was taken as the score. Six trials on each of three consecutive days was recorded.

RESULTS: An ANOVA was used with nested trials in days and days nested in subjects. A significant ($p<.01$) trend was found relating to the first three test trials of each day. With these trials removed resulted in the major amount of variance was between subjects. A table is given showing the expected reliability coefficients for each trial on each test day.

SUMMARY: While the sources of variance are small, the authors warn the problem with this study lies in the small sample size. The authors recommend to obtain reliability, the protocol should consist of three submaximal trials, then three maximal warm-up trials before getting your measurements.

CITATIONS: Four references.

STUDY: Jonsson, B. and Hagberg, M. The effect of different working heights on the deltoid muscle. Scand. J. Rehab. Med.; 1974, 9(Suppl. 3), 26-32.

KEYWORDS: EMG, deltoid muscle.

METHODS: The effect of different working heights on the myoelectric output from the clavicular portion of the deltoid muscle was investigated in 10 healthy adult males. Surface electrodes were used. The rectified and smoothed myoelectric signal was tested both with respect to the amplitude distribution and the mean value during the test.

RESULTS: The results of the investigation clearly show that the least myoelectric activity from the clavicular portion of the deltoid muscle occurred, on an average, when the object to be handled was placed on a working level of 110 cm. Compared to the anthropometric data, this level was approximately corresponded to that working level where the elbow was kept at an angle of approximately 90° - 100° of flexion.

SUMMARY: The amplitude distribution of the rectified and smoothed EMG and its mean voltage indicate that the working level of 110 cm was that which gave the least load on the muscle. The amplitude distribution of the rectified and smoothed myoelectric signal can be used to indicate whether the muscle is working statically or dynamically.

CITATIONS: Twenty-four references.

STUDY: Kamen, G. Serial isometric contractions under imposed myotatic stretch conditions in high-strength and low-strength men. European J. of Appl. Physiol. and Occup. Physiology; 1979, 41(2), 73-82.

KEYWORDS: Fatigue, reflex, eccentric contraction, negative work, elastic energy.

METHODS: Male subjects (N=24) were divided into two groups of 12 subjects each as high-strength and low-strength men, based on maximal voluntary contractile strength (MVC) of the right knee extensors. The experiment was designed to compare subject response to two different regimens which were intended to produce local muscular fatigue. One exercise regimen involved only isometric contraction, while the other exercise condition involved the administration of an imposed myotatic stretch upon a muscle group which was already contracting maximally.

RESULTS: Under nonfatigued pre-exercise conditions, significant tension increases at 6.5% for the high-strength and 11.0% for low-strength subjects were observed as a result of the imposed stretch. The fatiguing exercise resulted in significant decrements in strength on the order of 28.0% and 18.5% for the high-strength and low-strength groups, respectively. When a 1s imposed myotatic stretch during each trial was included, a greater strength decrement for the low-strength group (26.4%) than for the high-strength group (15.0%) was observed.

SUMMARY: High-strength individuals, who may be at a disadvantage in isometric endurance when compared to a low-strength group, are seen to be superior in endurance when an exercise involving serial isometric contractions with an imposed stretch is administered. A neural factor involving the stretch reflex is tentatively suggested as a plausible explanation accounting for the observation of that high-strength subjects fatigue faster than low-strength subjects under conditions of isometric exercise, while low-strength subjects fatigue faster than high-strength individuals in isometric exercise which is performed with an imposed stretch.

CITATIONS: Twenty-four references.

STUDY: Kamon, E. and Goldfuss, A.J. In-plant evaluation of the muscle strength of workers. Am. Ind. Hyg. Assoc. Journal; 1978, 38(10), 801-807.

KEYWORDS: Isometric back extension, elbow flexion, grip strength, male and female workers.

METHODS: The isometric (static) muscular strength of the back extensors, arm flexors and handgrip were measured, by using a special device, on industrial workers (463 male and 139 female) involved in physically demanding jobs. In the static strength measurement each group of muscles was measured for four seconds. Two trials were given with at least two minutes rest in between, for each muscle group tested. The highest value (in kg.) was recorded as the measured isometric (static) strength. Photographic pictures are given to indicate the subject posture while performing each test.

RESULTS: The average strength values for men were 23 kg., 11.9 kg., and 18.4 kg. higher, respectively for back extension, elbow flexion and hand grip, as compared to the women. Women's strength, in general, was about 60% of men's strength. The younger men (31 years and below) were significantly stronger than the older men (above 31 years) for all three strength variables measured. The younger women were significantly stronger than the older only for back extension.

SUMMARY: Men and women employed in physically demanding jobs in industry were measured for strength in back extension, elbow flexion and grip. The results showed that women were about 60 percent as strong as men; men below age 31 were stronger than those older, and finally the strength was similar among workers employed on different strength demanding jobs.

CITATIONS: Twelve references.

STUDY: Katch, F.I., McArdle, W.D., Pechar, G.S. and Perrine, J.J. Measuring leg force-output capacity with an isokinetic dynamometer-bicycle ergometer. Research Quarterly: 1974, 45(1), 86-91.

KEYWORDS: Dyanamometer, isokinetic, leg muscles, ergometer.

METHODS: A new apparatus is described which all extend the usefullness of the isokinetic dynamometer to measure force and work rate capacities of the leg. A Monark bicycle ergometer was mounted to a dynamometer. This formed the Isokinetic Dynamometer-Ergometer System. The subject sat at an angle on the ergometer to prevent mechanical advantage during the force output tests. A preset speed of 60 rpm was used during a trial of three or four pedal revolutions for eight to ten second periods. Three trials were given with one minute rest periods. The values obtained from the Cybex records were corrected with a value of .592. Forty-three men were tested.

RESULTS: Analysis of the force-output was checked for reliability between days, $r = .94$ and for the trials $r = .96$ and .91. The force output increased between trials, day 1, trials 2 and 3 were significant at $p<.05$ and day 2, trials 2 and 3, $p<.01$. Day 2 trials were higher than day 1 ($p<.01$) and average scores of day 2 were higher than day 1 ($p<.01$).

SUMMARY: Practice trials should be allowed to reduce the difference between the days. The equipment appears to satisfactorily measure the force-output of the work rates of the musculature.

CITATIONS: Nine references.

STUDY: Kitagawa, K. and Miyashita, M. Muscle strengths in relation to fat storage rate in young men. European Journal of Applied Physiology; 1978, 38(3), 189-196.

KEYWORDS: Body compositions, obese men, percent fat, threshold of obesity.

METHODS: The purpose was to compare obese and non-obese men in relation to muscle strength and fat storage rate. 59 Japanese men aged 18 to 22 were used as subjects. The underwater weighing method was used to determine body density. Electric (speedy type) and spring dynamometers were used to measure hand-grip, elbow flexion, trunk extension and knee extension strength. Testing was bilateral excepting trunk extension.

RESULTS: Body weight and lean body mass (LBM) correlated significantly. An increase with percentage of fat was seen with body weight, LBM, and fat. These were not significant differences in muscle strength between the 6 groups. Elbow flexion was the only measurement to reflect a difference between the groups.

SUMMARY: The obese men appear to have lower muscle strength for their LBM than the non-obese men. Additionally the obese male has less muscle strength than the non-obese male.

CITATIONS: 16 references.

STUDY: Knapik, J., Kowal, D., Riley, P., Wright, J. and Sacco, M. Development and description of a device for static strength measurement in the armed forces examination and entrance station. U.S. Army Research Institute of Environmental Medicine, Natick, MA. Technical Report; January 9, 1979.

KEYWORDS: Static strength, upper body, trunk, legs.

METHOD: The purpose was to develop a test for static strength to be used for the AFEES. The parts of the body tested involved the upper body, legs and trunk. A testing seat was developed and used with a tensiometer. Anthropometric measures were taken 948 male and 496 female recruits were tested in this device.

RESULTS: Test-retest trials given one day apart resulted in significant findings for the upper body and legs. The trunk showed a large variance with increasing strength from day 1 to day 2. Testing time on all groups was approximately 10 minutes.

SUMMARY: An aparatus to test static strength of the upper body, trunk and legs was developed. Reliability was found for the upper body and legs while work is still on-going for the trunk.

CITATIONS: 38 references.

STUDY: Kroemer, K.H.E. Human Strength: Terminology, measurement, and interpretation of data. Human Factors; 1970, 12(3), 297-313.

KEYWORDS: Muscle strength, isometric, isotonic, concentric, eccentric.

METHODS: The purpose was to clarify terminology, measurements and interpretation of data such that static and dynamic work could be properly related.

RESULTS: Terminology: Strength, isometric and isotonic, effort, work, dynamic, static, concentric, eccentric, phasic pulse, were defined and principles underlying some of them were given. Formulas for predicting dynamic performance from static strength were given but not without warning of the physiological problems involved. The author doubts the real predictability of dynamic from static measure.

Measurement: Equipment is usually meant to be used in only one way, the author feels the method should be fully described. Time of measurement should be 10 seconds or less. For oscillating pointers the peak reading is usually taken as the official reading. It should always be indicated whether peak or mean readings were used as maximal readings. The authors developed a check list which should be used in experiments to help insure the use of consistant and proper procedures.

Interpretation of the Data: Maximum and optimum exertion are defined as two separate and different meanings. The author discredits the use of the central nervous system as a measure of fatigue. While the use of CO_2 as a measure of energy consumption is considered very good its validity weakens the less dynamic the movement becomes. The use of circulatory system (heart rate) is recommended only in conjunction with energy consumption. Subject rating of strain related to work is said to be reliable enough for use: Measurements of work output may be used but it has been found to be indirect in the results yielded. For predictors of dynamic strength efforts the following may be considered. Research indicates that rankings of weight lifted were similar whether they were the subjects opinion or heart rate change.

SUMMARY: The amount of force exerted by a person is controlled by internal forces as well as by subject motivation and the experimenter. Therefore, standardization of techniques is very important if different research is in any way to be compared. This standardization includes the instructions given to the subject, equipment used to measure and the recording methods and equipment used. There has got to be a great need to have the relationship between static and dynamic strength established.

CITATIONS: Seventy-six references.

STUDY: Kroemer, K.H.E. Muscle strength as a criterion in control design for diverse populations. A. Chapanis (Ed.) in Ethnic Variables in Human Factors Engineering. Baltimore: The Johns Hopkins Press, 1975, 67-89.

KEYWORDS: Muscle strength, control design, lifting, population steriotypes.

METHODS: A review of literature dealing with the use of muscle strength in control design. Strength is defined and factors affecting it are listed. It is emphasized the necessity of matching the control and operator requirements together at the onset. Recommended weights to be lifted are hard to determine from the literature because of different populations, designs and sources in the research. Population steriotypes presently the author feels must be adhered to resulting in some problems with international design. For positioning controls the author suggests designing on the use of linear distances from reference points and ranges found within the population.

RESULTS: A procedure for designing equipment based on operator strength is given.

SUMMARY: Strength capabilities of an operator and force required to operate controls must be considered when designing equipment. The variables involved may include nationality or race, handiness, population steriotypes, control locations and biomechanical principles.

CITATIONS: 49 references.

STUDY: Kroemer, K.H.E. and Howard, T.M. Toward standardization of muscle strength testing. Medicine and Science in Sports; 1970, 2(4), 224-230.

KEYWORDS: Isometric, isotonic, posture.

METHODS: The purpose was to see if strength tests are significantly affected by their method of muscle contraction and second, whether strength measurement is affected by the index which represents the subjects selection. A force measuring device using strain gauges from a wooden adjustable footrest. 24 males of college age were used. Two postures were used. One, where the subject was standing upright and braced against a wall pushing with his hand and two, the subject placed both hands on the force plate and pushed while leaning forward. The force was applied in 3 manners, a) reach the maximum and hold, b) gradually increase, then release and c) jerk or apply force suddenly repeating once. Body posture and force were applied in random order. All tests were given in one test session.

RESULTS: Most subject's peak force during the hold force was during the second effort. Peak force for the increasing force was during a 4 1/2 to 7 seconds spread. The jerk force in the second thrust revealed a higher peak than the first. The upright posture resulted in about equal peaks for all three forces. The leaning posture revealed the highest force exerted during the jerk force.

SUMMARY: The authors feel the differences in the measures indicate the difficulty which occurs when attempting to compare research. The authors agree there needs to be a standardization of experimental procedures. The authors suggest for performance evoluation these indexes should be used:

(a) Use the average of the middle second if force is exerted for 3 or more seconds. Use the peak if the score exceeds 110% of the average at any time.
(b) Use the peak (i.e. the largest instantaneous amplitude) occurring anytime during the exertion period, if force is exerted for less than 3 seconds.

CITATIONS: 27 references.

STUDY: Kroll, W. "Isometric fatigue curves under varied intertrial recuperation periods." Research Quarterly; 1968, 39(1), 106-115.

KEYWORDS: Wrist flexors, endurance, fatigue curve.

METHODS: Endurance: The same definitions of absolute endurance and percent maximum strength held as defined by Tuttle, et al. (1955).

Fatigue Curve: Any fatigue curve represents the simple summation of energy depletion and energy recovery.

Steady State Condition: The appearance of a steady state implies a blance between the metabolic requirements for contraction and recovery under the conditions imposed.

Three experimental groups of 45 subjects each were given 30 repeated isometric wrist flexion trials. Each trial consisted of 5 sec of exertion followed by a rest period which differed for each group. The intertrial rest period was 5 sec in one group, 10 sec in the second group, and 20 sec in the third group.

In each experimental group subjects were ranked on the basis of the first two trials and divided into three subgroups of 15 each, representing high, middle, and low levels of wrist flexion strength.

RESULTS: Low level of strength groups always demonstrated a fatigue pattern significantly different from high and middle levels. High and middle levels displayed similar patterns differing only on absolute level of strength.

The analysis of the results of the five sec rest periods group suggests that both high and middle groups were able to level off from the dominent linear decline trend and display a less prominent but statistically significant quadratic pattern. The low level group, however, was not able to establish a steady state during the trial series demonstrating only a significant linear trend.

Kroll (1968) claimed that the same factors responsible for muscular fatigue cannot be operating to the same magnitude at different levels of absolute isometric strength.

He speculated that the causes of trend differences between the levels of strength may reside in considerations of local circulatory efficiency and a possible differing use of aerobic and anaerobic energy reserves.

RESULTS CONT: Finally, he emphasized that investigations considering muscular fatigue at levels of strength rather than a composite fatigue curve may be helpful in unraveling the ball of conflicting evidence of muscular endurance.

SUMMARY: Although females were not as strong as males they did show the same fatigue patterns as the men. Right and left hands (except one set) also reflected the same fatigue patterns. The author states that while the patterns were similar the use of one composit pattern in reporting data is not representative of the data.

CITATIONS: 11 references.

STUDY: Kroll, W. Recovery patterns after local muscular fatigue for different levels of isometric strength in college age females. American Corrective Therapy Journal; 1971, 25(5), 132-138.

KEYWORDS: Wrist flexion, isometric, sex differences, fatigue.

METHODS: Isometric wrist flexion strength was measured by the use of strain gauges. 645 degree dorsi flexion was kept by all subjects during testing. Each subject was tested 6 days. Five 5 second exertion trials with a rest of one minute were administered each session to determine strength on days 1 and 2. The testing schedule ran two tests 48 hours apart. Then a week between the next two tests. Thirty-three women, average age 19.7 years, were separated into 3 groups of low, medium and high strength.

RESULTS: While other research has indicated that psychiological factors affect fatigue series tests this was not found to be so in this study. The recovery patterns extended up to the quadratic degree components with statistical significance. The low strength group exhibited low trend recovery. Percentage of fatigue was highest for the high strength group and lowest for the low strength group.

SUMMARY: Since the recovery pattern appears to be affected by many factors the author feels an equation to describe this would not be successfully arrived at. The variables to be considered include level of strength, subject's sex and muscle group. The comparisons of male and female data showed significant differences.

CITATIONS: Eleven references.

STUDY: Kroll, W. and Clarkson, P.M. Age, isometric knee extension strength and fractionated resisted response time. Experimental Aging Research; 1978, 4(5), 389-409.

KEYWORDS: Knee extension, Age, rectus femoris muscle, registered response.

METHODS: The purpose was to look at the effect of age and activity level affecting isometric knee extension strength and response time. Sixty male subjects, ages 18-38 and 55-79, were divided into young and old, inactive and active groups. Each subject was tested two separate days on right knee extension trials. A strain gauge was attached to a Beckman Type R Dynograph which was used for strength measurements. The motor point of each subject was found by applying electrodes to the subject right of the rectus femoris muscle. The older subjects motor point was found anatomically. Each subject was exposed to a board containing three lights. The subjects were to respond to the signal light by kicking a padded target located below the light. Resisted response was produced by placing the heel of a steel plated shoe against an electromagnet, which was set at 10% of the subject's knee strength. When the subject pulled away, reacting to a signal, the response was clocked at the electrodes which transmitted the signal to oscillioscope to read the muscle action potential. The removal of the heel from the magnet set another clock to measure total reaction time.

RESULTS: Inactive subjects had a higher body fat than active subjects. Reliability for knee extension strength was .94 knee strength for the old active was greater than the old inactive group. Reaction time for the slowest to fastest was old inactive, old active, young inactive, young active with each group slowing during simple resisted reaction time while choice response time increased.

SUMMARY: Decrease in knee extension strength appears to be hindered by consistent physical activity. The increase in total reaction time is the resisted reaction time is apparantly due to an increase in length of motor time component. The authors feel that the use of resisted reaction time should be employed in future research.

CITATIONS: Twenty-four references.

STUDY: Lamphiear. D.E. and Montoye, H.J. Muscular strength and body size. Human Biology; 1976, 48(1), 147-160.

KEYWORDS: Sex differences, arm strength, grip strength, anthropometric measures.

METHODS: The study looks at the relation between anthropometric measurement and arm and grip strength in men and women. Ages ranged from 10 to 60, and subjects were normal and healthy. A Stoeling grip dynamometer was used to take grip strength. The grip was adjustable to account for size. Recorded was the greatest of two readings for each hand. Arm strength of the upper flexors of the arm was taken. The elbows were at 90° angles with the upper arm parallel to the floor, the hands, at shoulder width, grasped a bar and pulled. The force in kilograms was read from the dynamometer. The larger of two scores was recorded. The twelve size variables found in relation to age, the summed grip strengths, and the arm strength were taken to enable the development of a regression model.

RESULTS: The strength variables and five of the size variables were found to be of primary importance for the regression equation. Strength was found to be predictable from the size variables, arm and grip strength being equal. Regression equations were developed to estimate the strength index from the size variables for sex and age was given in table form.

SUMMARY: The use of few size variables and strength enabled the authors to develop a simple and generalizable model for prediction. It is felt that the results are not as specific as those of Tecumseh's population. The observed strength can be divided by standard strength index which will give a linear result of the percentage duration from the mean.

CITATIONS: Twenty-three references.

STUDY: Larsson, L., Grimby, G., and Karlsson, J. Muscle strength and speed of movement in relation to age and muscle morphology. Journal of Applied Physiology; March, 1979, 46(3), 451-456.

KEYWORDS: Isokinetic; isometric and dynamic strength, human skeletal muscle, muscle fiber types.

METHODS: One hundred fourteen males, ages 11-70 years were used. anthropometric measurements were taken. Mechanical measurements were made using an isokinetic dynamometer. The maximum isometric and dynamic strength and MEV were measured on the left knee extensor muscles. The peak isometric values was used as the definition for each individual's maximum strength. Maximum knee extension velocity was taken by having the subject extend the leg as quickly as possible. Histochemical analysis was made on all subjects ages 20-65. Biopsies were taken and kept frozen until analysis. These were used to assess the fiber diameter.

RESULTS: For comparison of age changes in isometric and dynamic strength, it was necessary to use curvilinear regression fitted to each individual's data. Differences in anthropometric varaibles were found in the 10-19 year olds to be smaller than the adults (age 20-49) group and old (50-69) group. No difference was found between the 50-60 year olds and 70 year olds. Isometric and dynamic strength increased with age up to 20-29. Then, leveled to the 40-49 year group and finally decreasing with the older groups. The biopsy data revealed a shift toward low percentage fast-twitch muscle fibers while slow-twitch muscles increased with an increase in age. Fast twitch muscle fibers showed a significant ($P<.01-.001$) correlation with strength, isometric and dynamic power. Where fast-twitch fiber was eliminated from analysis the strength decline was still significant, which reflects the idea of other factors being related other than muscle atrophy.

SUMMARY: Changes in isometric and dynamic strength was definately seen occurring with age. The authors feel the data cannot be generalized due to the nonrandom selection of subjects excepting the 70 year old group. Most studies in strength performance, usually using hand grip, show the peak strength in the 25 to 30 year olds. Although research on muscle fiber change regarding age is scarce, it appears that the findings of this study regarding muscle twitch fibers conforms to available research.

CITATIONS: Thirty-eight references.

STUDY: Larsson, L. and Karlsson, J. Isometric and dynamic endurance as a function of age and skeletal muscle characteristics. Acta Physiol. Scandanavia. 1978, 104(2), 129-136.

KEYWORDS: Fiber area, fiber type distribution, human skeletal muscle, isokinetic, lactate dehydrogenase.

METHODS: Fifty male subjects aged 22 to 65 years who were all clerks by occupation were used. The maximum isometric strength and endurance were taken on both legs simultaneously while the subject pressed against a bar. Maximum dynamic strength and endurance were taken with the use of a dynamometer. This measure was made on knee extensions. Results from a previous (Larrson, et al., 1978 a, b) are used here for correlation. The subjects are the identical with these. Previously, biopsies were taken to get data on fast and slow twitch fibers, enzimes, and chemical present in the muscle tissued. Biopies were also taken here.

RESULTS: There was a decrease in Type II (fast twitch) A, and B fibers with increasing age, additionally, the area Type II covered also decreased. Anaerobic activity decreased with age while the aerobic remained the same. Declines in maximum isometric and dynamic strength correlates significantly. ($P<.001$) with the decrease in Type II fibers as seen in old age. Isometric and dynamic endurance was seen to increase with age, but this was not significant. Relative force decline was seen to increase with Type II, and fiber area significantly at $P<.05-.01$.

SUMMARY: Previous research has indicated a decrease in endurance with age. This was not supported here, even when corrections for decreases in maximum strength were made. The author does list some research which is in agreement with the results here. With the change in fiber area, the hypothesis porpocting that Type I (slow twitch) acts as a recipient of lactarte produced by Type II fibers was upheld in this study. Finally, maximum strength did decrease with age as expected.

CITATIONS: Thirty-six references.

STUDY: Laubach, L.L. Body composition in relation to muscle strength and range of joint motion. Journal of Sports Medicine and Physical Fitness; 1969, 9(2), 89-97.

KEYWORDS: Anthropometric measures, hip, trunk, flexors, extensors, tensiemeter.

METHODS: The purpose was the investigation of body composition and physical performance. Forty-five males, aged 17 to 35 years were used. Anthropometric measures were taken, along with skin fold, lean body mass (LBM) body density and surface area. For the physical performance strength and range of joint motion for hip and trunk flexors and extensors. A cable tensiometer was used to measure muscle strength.

RESULTS: One hundred and twenty-six zero-order coefficients were computed resulting in 44 being significant beyond .05. The highest correlation was .698 for hip flexion and LBM - suprailiac. The 4 strength measures and the LBM^2 were all significantly correlated. When stature was constant then significant correlations were reached between physical performance and somatotype components. Range of joint measurements did not correlate with any anthropmetric measures or body composition. Second order correlations did produce significance in some of the measures when stature and weight were constant with physical performance, anthropometry and body composition.

SUMMARY: Stature, LBM body surface and mesomorphy were significant with muscle strength. With stature constant then the somatype components would correlate significantly with the muscle strength measurements. Physical performance and anthropometric or body composition with body weight out reach significance. Six significant correlations were found among the range of joint and anthropometry or body compositions with weight and stature constant. The use of multiple regressions to predict physical performance from anthropometry and body composition were found to account for 26% to 56% of the performance variance.

CITATIONS: Twenty-two references.

STUDY: Laubach, L.L. Comparative muscular strength of men and women: A review of the literature. Aviation, Space and Environmental Medicine; 1976, 47(5), 534-542.

KEYWORDS: Male and female, muscular strength.

METHODS: The purpose is to review studies dealing with comparison of static and dynamic muscle capacities in men and women.

RESULTS: All but one study used college students, the other used industrial workers. Women's leg strengths appear to be closer to that of the men than the arm strength does. Women have 35 to 79% upper body strength, 57 to 86% lower body strength, trunk strength was 37 to 70%, and total body strength was 35 to 86% that of men.

SUMMARY: Women have approximately 2/3 the strength of men. The author does state that because of the broad ranges found, he recommends that the designer refer to individual data when more specific information is needed. A step process is offered to the designer so he may derive the fifth percentile from the data.

CITATIONS: Twelve references.

STUDY: Laubach, L.L., Kroemer, K.H.E., and Thordsen, M.L. Relationships among isometric forces measured in aircraft control locations. Aerospace Medicine; 1972, 43, 738-742.

KEYWORDS: Isometric force, force on hand-operated equipment.

METHODS: The purpose was to measure the peak forces exerted on hand-operated aircraft controls. A strain guage force transducer and Brush Mark 200 recorder were used. Six different controls were used to take measurements on anthropometric measurements on 51 paid male subjects were taken. Each subject took a seat and was then instructed as to the movements he should make.

RESULTS: For estimating force exertion, body weight was thought to be the single best prediction with r = .34 to .49. The correlations for grip strength and force exertions was .21-.36 which accounted for 4-13% of variation.

SUMMARY: The authors state weight was the best single prediction for arm force.

CITATIONS: Seventeen references.

STUDY: Laubach, L.L. and McConville, J.T. The relationship of strength to body size and typology. Medicine and Science in Sports; 1969, 1(4), 189-194.

KEYWORDS: Static strength, anthropometric measurements.

METHODS: The purpose of this study was to examine the correlation between muscle strength measured by the static-contraction method and various body size characteristics. Eleven cable-tension tests of body strength were conducted. These tests included the flexion of hips, trunk, elbow, shoulder, knee and ankle; the extension of hip, trunk, knee and ankle (planter flexion); and the shoulder inward rotation. The strength score used was the maximum amount of force (without jerking) that the subject could exert against the resistance of the pulling assembly. The strength testing was unilateral, right side only, with the exception of trunk flexors and extensors.

RESULTS: Body weight correlated significantly with all of the static-strength measures except hip extension and knee extension. The computed measure of lean body mass correlated significantly with all of the muscle strength measurements. The mean and the standard deviation of the thirteen static strength measurements are given in tabular form. The total lever arm linkage of torso length produced several significant correlations with muscle strength. The somatotype components for endomorphy and mesomorphy both produced several significant correlations with the measures of muscle strength.

SUMMARY: The results of the present study indicated that the measures of body size, typology and composition used in this analysis are not effective predictors of static strength.

CITATIONS: Thirty-one references

STUDY: Less, M., Krewer, S.E., and Eickelberg, W.W. Exercise effect on strength and range of motion of hand intrinsic muscles and joints. Arch. Phys. Med. Rehabil.; 1977, 58(8), 370-374.

KEYWORDS: Finger joints, hand, joints, motion, motor activity, muscles.

METHODS: The purpose of the study was to study the effects of hand exercises on hand strength and range of motion. Twelve men participated in a 3 session per day for four weeks program. An adjustable isometric hand gym was used for the exercises. Four sets of exercises were given, one for stretching and three were isometric. Strength was measured with a dynamometer.

RESULTS: Seven of twelve strength measurements significantly improved with exercise. The little finger appeared to improve more than the others. There was a significant improvement in the range of motion after exercise.

SUMMARY: This evidence shows the increase in strength occurred quite rapidly and the weaker the hand the more the increase.

CITATIONS: Eleven references.

STUDY: Lind, A.R., Burse, R., Rochelle, R.H., Rinehart, J.S. and Petrofsky, J.S. Influence of posture on isometric fatigue. Journal of Applied Physiology; 1978, 45(2), 270-274.

KEYWORDS: Isometric strength, isometric endurance, fatigue.

METHODS: The purpose was to examine how posture influences muscular strength and endurance and cardiovascular changes. Four men ages 25-37 years, were trained for 1 week on handgrip isometric contractions and then trained 3 times per week for another 2 to 3 weeks. A Hand dynamometer was used while the subject was in a seated position, 3 positions on a tilt table and in a 45° head-up, recumbant or 15° head down position. Strength was measured at maximum, endurance at 25 and 40% of maximum and with tension at 40%. Forearm blood flow and heart rate (ECG) was measured throughout the experiment.

RESULTS: Repeated contractions and posture did not affect hand grip strength. There was significant occlusion of blood flow at 40% and 25% of strength. There was no significant changes in blood pressure although heart rate did increase some.

SUMMARY: While posture did not affect performance there was found to be a significant affect in blood flow of the working area.

CITATIONS: 13 references.

STUDY: Lindh, M. Increase of muscle strength from isometric quadriceps exercises at different knee angles. Scandinavian Journal of Rehab. Medicine; 1979, 11(1), 33-36.

KEYWORDS: Static and dynamic strength, quadricep muscle.

METHODS: The purpose was to see if training position had an effect on isometric strength on the quadricep muscle and dynamic strength of this muscle. Ten females, aged 20 to 35 years were used. A Cybex II modified with a strain-gauge was used for dynamic and static measurements. Isometric tests were taken at 15° and 60° and isokinetic measures were recorded in a range from 90° to position. Training was on the Orthotron, each subject being trained for 15° on one leg and 60° on the other. Training lasted three times per week, lasting 11 to 19 times.

RESULTS: Isometric exercise showed increase in torque for both legs at a significance of $p<.01$. The angles produced increases in torque also, and each was significant. Dynamic force at 180°/sec. was not changed but there was significant increases ($p<.01$) at the 30°/sec. curve.

SUMMARY: Overall, exercise in the 60° position was improved strength at that position while exercise in the 15° position did not affect either. Position effect does appear to have an affect on training which agrees with previous research.

CITATIONS: Sixteen references.

STUDY: MacIntosh, D. The structure and nature of strength. Journal of Sports Medicine; 1974, 14(3), 168-177.

KEYWORDS: Strength.

METHODS: To review and analyze research in strength.

RESULTS: Speed and strength have been found to not be predictive of one another. While some of the research conflicts with this statement, the author feels more up to date equipment can settle the disagreement. Relationships between limb speed and strength appears to be relatively high where the subject has to move the body itself or some other substantial mass. Studies in strength training programs and effect on speed have conflicting results. While weight training programs developed claim success with improvement in certain sports the author points out that the lack of controls in these experiments limits their claims.

SUMMARY: Strength tests should not be used when assessing speed performance of a limb. Up to 50% of variance in limb performance may be attributable to movement of total body mass or when mass is added to the limb moving. When strength improves it does not correlate with improvement in performance. There are no existing group of tests which can yet measure general strength factors and the author contends the test batteries which do exist should be revised.

CITATIONS: 86 references.

STUDY: McClements, L.E. Power relative to strength of leg and thigh muscles. The Research Quarterly; 1966, 37(1), 71-78.

KEYWORDS: Body power, muscle strength, flexors, extensors.

METHODS: The purpose is to compare body power as determined by jumping height with strength of leg and flexor and extensor muscles in the thigh. Secondly, to compare power strength effects an agonistic and antagonistic muscle groups. Eighty-six men were measured on a vertical jump test and leg strength measured by the Clark cable-tension technique. Two measurements were taken for each test. The group was divided into four training groups each emphasizing training of a special muscle group (i.e. extensors) and one group was a control.

RESULTS: Reliability of jumping scores was .86 and strength scores had a reliability of .90. The treatment groups were not significantly different to begin with, but achieved significance after training. There was no difference between training groups. A correlation between initial-strength and initial power were significant excepting the flexor group. The gains in power were not significantly related to the agonistic or antagonistic strength.

SUMMARY: All training programs were equally effective and strength, while related to power, the gains of each were not related.

CITATIONS: Eleven references.

STUDY: McGlynn, G.H. The relationship between maximum strength and endurance of individuals with different levels of strength. Research Quarterly; 1969, 40(3), 529-535.

KEYWORDS: Flexors of wrist, endurance, training.

METHODS: Endurance: Endurance in this study is defined by the definition used by Tuttle (1955) for the Absolute Endurance Index.

Percentage of Maximum Strength Held: Defined by the same definition used by Tuttle (1955).

The total number of subjects tested was 60 males, ranging from 18 to 21 years of age. They were randomly divided into two groups, experimental (E) and control (C). On the basis of maximal strength scores, the 30 subjects in group E was divided further into two subgroups, high level strength and low level strength. The high level strength group consisted of 15 subjects with the highest strength of 24-39 kg, the low level group of subjects with maximal strength scores of 23 kg and below. The subjects were asked to make a maximal voluntary effort in the flexion of the wrist for 100 sec. Group E took a training program of 20 days.

RESULTS: The relationship between endurance and maximum strength for group E before training was significant (r = 0.77) as was that between maximum strength and endurance for group C (r = 0.72). Relationships between maximum strength and endurance during and after training period were also significant. The values of r for the tests performed every 5 days were 0.8, 0.74, .78, .80 and .73 in sequence of order.

The relationship between maximum strength and percentage of maximum strength held demonstrated the ability of the low level strength group to maintain a higher percentage of their maximal strength than the high level group. The correlations obtained in this study were negative, with tests performed before training, after 5 days of the training program, and after completion of training significant. (r = -.42*, -.36*, -.2, -.29 and -.63*; * = significant correlation).

Factors Affecting Endurance: During a maximum isometric contraction the intramuscular pressure rises above the arterial pressure in the muscle. The exerted force results in the occlusion of block to the muscle. As a result a major part of the energy for sustained contraction depends upon the amount of aerobic energy reserves in the muscle. Thus, the factors determining endurance are the energy available and the demand made upon it.

McGlynn 1969 Cont.

RESULTS CONT: It may be assumed that the build-up in biochemical fatigue products in an isometric contraction is related to the amount of force exerted by the muscle. Individuals exerting high levels of maximum strength therefore would produce more fatigue elements than those of a weaker group.

In the case of the stronger group one could expect on earlier onset of fatigue as a result of the larger amount of fatigue products present in the muscle.

SUMMARY: Subjects who exerted greatest strength were found to be unable to maintain as large a percentage of the strength during endurance as those subjects with a less maximum strength. Training was found to produce no significant difference between the two groups. The low strength group made a larger improvement in maximum strength than the high strength group did.

CITATIONS: 13 references.

STUDY: McGlynn, G.H. and Murphy, L.E. The effects of occluded circulation on strength and endurance at different levels of strength. American Corrective Therapy Journal; 1971, 25(2), 42-47.

KEYWORDS: Wrist flexors, endurance, isometric strength.

METHODS: Definitions: the same definitions of absolute endurance index and percent maximum endurances held as defined by Tuttle, et. al., 1955.

The subjects (60 males ranging from 18-21 years of age) were divided into two groups, non-occluded and occluded. On the basis of strength scores they were further divided into two subgroups, high and low level strength. The subjects were tested for maximum isometric strength and endurance of the wrist flexors for 100 seconds. Subjects in the occluded group had a sphygmomanometer placed around the upper arm. The cuff was inflated to a pressure 15 mmHg. above the subject's systolic pressure immediately before testing and remained above this level until the end of the test.

RESULTS: The reliability coefficient for test-retest of the non-occluded group was 0.9. A significant relationship was found between maximum strength and absolute endurance index for both groups. A negative and in most cases, significant relationship was existed between maximum strength and percentage of maximum strength held. The correlation coefficient for the occluded group was ($r = -.28$) which was not significant. However, the correlation coefficient for the non-occluded group was negative and significant ($r = -.43$). The absolute endurance of the high level strength subgroups was not significantly different between the occluded and non-occluded groups despite the artificial occlusion of blood supply in one group. This was also true for the two low level strength subgroups. The results indicated that individuals with great strength cannot maintain as large a percentage of it as individuals with less maximum strength.

The Factors Affecting Endurance are: 1) maximum strength and absolute endurance, and 2) maximum strength and percentage of maximum held. For the first, the muscular contraction is maximal, the intramuscular pressure rises above the arterial pressure in the muscle. The exerted force results in the occlusion of blood to the muscle. As a result, a major part of the energy reserve for sustained contractions depends upon the amount of anaerobic energy reserves in the muscle. When occlusion occurred, the factors determining endurance are the energy available and the demands made upon it. If tension created by an isometric contraction is not sufficient to

McGlynn and Murphy 1971 Cont.

RESULTS CONT: occlude blood and cannot prevent replenishment of energy reserve, endurance should not be affected. However, in the occluded muscle, whether the occlusion is produced artificially or naturally, endurance should be related to the force of contraction.

The maximum strength and percentage of maximum held may be assumed that the build-up in bio-chemical fatigue products in an isometric contraction is related to the amount of force exerted by the muscle. Individuals exerting high levels of maximum strength therefore would produce more fatigue elements than those of a weaker group.

SUMMARY: Four groups of subjects, divided by high and low strength, and occluded and unoccluded strength, were tested for strength and endurance. A significant positive relationship was found between maximum strength and endurance. The strength differences between the two high strength groups and the two low strength groups was not significantly different despite the artificial occlusions.

CITATIONS: Fourteen references.

STUDY: Mendler, H.M. The hydraulic isometric force testing unit K-100. Physical Therapy; 1972, 52(4), 393-398.

KEYWORDS: Isometric force testing.

METHODS: This paper describes the hydraulic isometric force testing unit K-100.

RESULTS: The description of the unit included a list of the parts of the table in the order of their assembly, the function of the parts, and the advantage and limitations of the unit. A brief background survey of the factors leading to the development of the unit is also included.

SUMMARY: A well-designed, self-contained hydraulic force testing unit with excellent stabilization features has made possible the testing of maximum isometric force of muscle groups with great accuracy. The relative expense of the unit was outweighed by a design which allowed testing of all major muscle groups of the body except fingers and toes.

CITATIONS: Eight references.

STUDY: Moffroid, M.T. and Kusiak, E.T. The power struggle: Definition and evaluation of power of muscular performance. Physical Therapy; 1975, 55(10), 1098-1104.

KEYWORDS: Muscle power, muscle performance, isotonic and isometric.

METHODS: The purpose was to discuss five different kinds of muscular performance.

RESULTS: Measurement of power can be made with the use of an isokinetic device which measures the power through an electric device.

Power: work done as measured by the rate performed. A computation which can be used is: $\frac{\text{work}}{\text{time}}$ where work = force x distance. Using an instrument to measure the power, the experimenter then has the ability to relate torque to any point in the range of motion. Work can then be calculated using the readings from such a measurement device.

Peak Power: found by: $\frac{\text{peak torque}}{\text{time}}$ and it is the highest level of torque produced during the contraction. This measure can be used as a measure of work, thus eliminating the duraction of the range of motion. It must be understood that peak torque is not the same as work, but a substitute for it. Peak power cannot be made from isotonic contractions, only isometric because the work load is reflected only in the weakest point of the range instead of the maximum point in isometric movement.

Average Power: This is endurance in the averaging of many work repetitions over a selected period of time.

Instantaneous Power: This is the power exerted between the initiation of the movement and the peak torque. The formula is: $\frac{\text{Peak Torque}}{\text{time}}$
Instantaneous power cannot be used when the peak torque has been displaced due to velocity changes.

Contractile Power: "The ability of the muscle to develop force in a specified period of time and the ability to maintain the tension at velocities which are within the ranges of functional activities."

SUMMARY: Definitions have been given to five measures of power with suggested measures.

CITATIONS: Eight references.

STUDY: Montoye, H.J. and Lamphiear, D.E. Grip and arm strength in males and females, age 10 to 69. The Research Quarterly; 1977, 48(1), 109-120.

KEYWORDS: Grip strength, arm strength, males and females.

METHODS: Arm and grip strength data was collected in the community of Tecumseh, Michigan. This was to give a more representative sample of the American Population. Six thousand, five hundred eight townspeople (82% of the population) were tested. All subjects were healthy and normal. A stoelting grip dynamometer was used for grip strength and for measurement. Upper arm strength was taken by the subject by pulling a bar downward. The bar was connected to a cable which held a dynamometer. Scores were grouped depending on age and sex. A canonical analysis was used to remove the effects of body size and fatness from the strength scores as correlated with anthropometric measurements. Relative strength index was a sum of the arm and grip strengths after adjustment.

RESULTS: Tables for percentile scores were given for force values in kg, for strength, scores divided by body weight, and relative strength scores.

SUMMARY: The authors feel these tables represent, more accurately than any previously published, the strength values of healthy Americans. Little decrease in strength can be seen between the ages of 20 to 50. Ten to 12 year olds were seen to have lower scores than older children. This was attributed to size. For girls, pull-ups were not seen as an adequate fitness test because more than half are unable to exert more force than that equal to their body weight.

CITATIONS: Thirteen references.

STUDY: Morris, J.R.W. Accelerometry - A technique for the measurement of human body movements. Journal of Biomechanics; 1973, 6(6), 729-736.

KEYWORDS: Lower limbs, accelerometer, movement.

METHODS: The purpose is to develop a measurement of the lower leg movement which was simple and interfered minimally with the gait so as to be used outside the laboratory. Five accelerometers are mounted on a platform which is then mounted onto the antero-medial surface of the tibia which is held in place by a cast. Signals are recorded on a portable recorder. Analysis of the signals is performed by a digital computer. The computer can give a true-speed moving picture of the limb, a graphical and numerical representation of the measured movement.

SUMMARY: This measuring instrument can be helpful in making force estimates of the joints, muscles and ligaments. The recordings offered the experimenter graphs of angular velocity, directional cosine, translational acceleration, velocity, position, and a visual representation.

CITATIONS: Twelve references.

STUDY: Mortimer, R.G. Foot brake pedal force capability of drivers. Ergonomics; 1974, 17(4), 509-513.

KEYWORDS: Foot pedal, foot force.

METHODS: The purpose was to determine the range of foot forces exerted by U.S. drivers and is compared to three other similar studies. Five hundred ninety-nine male and females, aged 16-89 years, were used as subjects. All subjects were seated on an adjustable pedal angled within the common range for brake pedals. Each subject was seated and adjustments were made, then each subject exerted maximum force for three seconds, this was performed twice. The second time using motivation instructions. The same was performed for both legs.

RESULTS: There was a high force correlation (r=.93) between the right and left feet. For the fifth and 50th percentiles at standard instructions and motivation instructions were 311N, 681N, 454N and 863N respectively for females. Males at the fifth and 50th percentiles on standard instructions had force values of 592N and 1241N and motivation instructions at the fifth percentile were 840N. The 50th percentile was not measured as many of the males exceeded the 1334N limit of the force gauge.

SUMMARY: The results indicate the level of force needed to stop a vehicle should not exceed 400N thus covering 95% of females and 99% males will be able to brake sufficiently. The author believes the evidence is sufficient to assist in making revisions of brake pedal standards.

CITATIONS: Nine references.

STUDY: Murray, M.P., Baldwin, J.M., Gardner, G.M., Sepic, S.B., and Downs, W.J. Maximum isometric knee flexor and extensor muscle contractions: Normal patterns of torque versus time. Physical Therapy; June, 1977, 57(6), 637-643.

KEYWORDS: Isometric, knee, muscle contractions.

METHODS: Twenty-four normal males, ages 20-35 and twenty-four healthy normal males, ages 45-65 were used. A Cybex dynomometer was used to record torque and an electrogoniometer was used to measure knee joint. Electrogoniometer was secured to the knee, the pivot point was placed over the lateral epicondyle of the femus allowing the plastic arms to be parallel to the axis of the leg and thigh. Recording was done on a Grass model, F polygraph. Subject was seated and stabalized, then told to flex or extend according to the instructions given. Torque was taken at 30, 45, and 60 degrees. Full extension was defined as 0 degrees. Torque produced from weight of the subjects leg was subtracted from flexor torque and added to extensor torque readings.

RESULTS: Patterns of torques during a five second contraction resulted showing no single pattern, only one peak (84%) maintained for less than 1 second. The other 10% had more than one peak or a peak of longer than 1 second. Knee joint position has the effect on knee flexor and extensor muscles of affecting the extensor muscles more reflected in the higher torque reading. Sequence of testing angles did not affect the torque. Age had the influence of the higher the torque the younger the man. The older group averaged 75-80% torque of the younger man. Torque differences were seen between week 1 and week 2, leaving week 2 showing a higher measure.

SUMMARY: Although many studies have looked at the knee flexor and extensor muscles, time has not been one of the factors looked at. As reflected in this study, the time varied greatly from subject to subject although the peak was always less than one second. The decrease in muscle strength with age agrees with the findings of Cuddingan's (1973). The subject responses for knee joint curve do not follow the previously published material, but peaked at points where the peak was not expected.

CITATIONS: Thirty-three references.

STUDY: Noble, L. and McCraw, L.W. Comparative effects of isometric and isotanic training programs on relative-load endurance and work capacity, Research Quarterly; 1973, 44(1), 96-108.

KEYWORDS: Isometric and isotonic muscular strength, endurance, leg, bench press repititions.

METHODS: Isotonic Strength: Isotonic strength in both the bench press and leg press movements was assessed by determining the maximum amount of weight that could be lifted through one complete range of movement (1-RM).

Isotonic Endurance: Was measured by the number of repetitions the subject could complete while maintaining a cadence of 30 repetitions per minute against a relative loading of 1/2 of 1-RM for the bench press and 2/3 of 1-RM for the leg press.

Relative Isometric Endurance: (Same definition used by Carlson and McCraw and Start and Graham) was assessed by determining the time (in seconds) the subject could hold a prescribed weight while in position of 90° at the elbow and knees. A relative load of 1/2 isometric strength was used for the bench press test and 2/3 was used for the leg press.

The subjects were college males (N = 64), ages 17-31 years. Subjects trained for a period of 9 weeks, three days a week. Two different training programs were used: isometric training and isotonic training. Tests of both isometric and isotonic strength and isometric and isotonic endurance were administrated before and after the 9-week training period. Each subject was given the isotonic tests on one day and the four isometric tests the following day. A 5-min rest interval was allowed between successive measurements on each day.

RESULTS: The correlations between isometric strength and isometric endurance ranged from -0.51 to .06 on the pretests and from -0.39 to -.14 on the post test with only one coefficient on each of the testing administrations reaching statistical significance. It therefore appears that a stronger individual cannot continue sustained contractions with a load adjusted as a percent of his maximum strength as long as an individual who is weaker.

The data analysis revealed that:

(1) The isotonic training program was superior to the isometric program with respect to its effect on relative-load isometric bench press endurance, isometric bench press work capacity, and isotonic bench press work capacity.

(2) The effects of the two training programs on the other endurance and work capacity measures were not different.

Noble and McCraw 1973 Cont.

RESULTS CONT: (3) *Neither of the training programs affected the relationship between isometric strength and relative-load isometric endurance and btween isotonic strength and relative-load isotonic endurance.*

SUMMARY: The following conclusions are supported by the data of this study:

(1) The development of muscular endurance is not necessarily proportional to the development of muscular strength, but is a function of the method of training. In other words, an increase in strength does not guarantee a proportionate increase in endurance.

(2) Work capacity is better improved by training with a program of progressive resistance weight training exercises than by training with a comparable program of maximum resistance isometric exercise.

(3) The relationship between strength and relative-load endurance is not different in trained and untrained individuals.

CITATIONS: 21 references.

STUDY: Nordesjo, L.O. and Nordgren, B. Static and dynamic measuring of muscle function. Scand. Journal of Rehabilitative Medicine; 1978, 10(6), 33-42.

KEYWORDS: Static, dynamic, muscle function.

METHODS: Review of literature for measuring isometric muscle function before and after injury, amputation, and disease. The literature covered regards strength changes in, a) older men before and after surgery dealing with the prostate, b) rheumatic arthritis patients and normals, c) muscle strength and work output of mentally retarded, d) myasthemia gravis patients and normals, e) above knee amputations and, f) fibrile infections resulting in partial imparement. Military research has shown a reliability of .8-.93 over a short time and a reliability of .6 when repeated after months and years.

Static and Dynamic muscle strength are easier to measure, as there are more ways to take the measurements. The use of the Cybex II with supplemental devices allows for this kind of flexability.

Presently, the authors have begun a study dealing with isometric and dynamic strengths and endurance with normals and patients with chrodromalacia of the patella with varying degrees of arthrosis. Cybex II was used for measurements.

RESULTS: Reproducibility is .88 and .86 for static and dynamic strength respectively. As degree of injury increases, the maximal isometric strength in knee extension decreases. Differences found in dynamic measurements are the same between healthy and injured limbs.

SUMMARY: Because of the high correlation between right and left, the authors recommend comparisons be run in a series when looking at a healthy vs. unhealthy limb to eliminate individual differences between subject.

CITATIONS: Twenty-one references.

STUDY: Nordgren, B. Anthropometric measures and muscle strength in young women. Scand. J. of Rehabil. Medicine; 1972, 4, 165-169.

KEYWORDS: Isometric muscle strength, anthropometric measurements, sex differences.

METHODS: Twenty-three women aged 17 to 24 years were utilized. The skeletal width and the skinfold thickness were measured (in mm) with a vernier caliper. The lengths of the following bones were measured: humerus, radius, femur, and tibia. The circumferences of the chest and the abdomen were measured. The skinfold thickness is a composite of two layers, each including skin and subcutaneous adipose tissue. The measurements in this study included all four layers. The maximal isometric muscle strength was measured by means of a pressductor transducers. Each test component comprised three maximum efforts with a duration of at least three seconds each, and the highest value was recorded.

RESULTS: The anthropometric data and the isometric muscle strength measurements are given in tabular forms. A comparison with corresponding data for a group of young men were given. The muscle strength was lower (more pronounced in the upper extremities) in the female group. Except for the skinfold thickness, which was significantly larger in the women, the differences in anthropometric data between the two groups was much less than the difference in muscle strength. Most anthropometric measurements were smaller in the female group. When predicting body weight, the width of the femoral condyle was found to be preferable to the body height.

SUMMARY: This investigation had two aims, namely to obtain normal values of anthropometric measurements and maximal isometric muscle strength for women using a standard method, and to compare these values with corresponding values for men.

CITATIONS: Six references.

STUDY: Nordgren, B., Elmeskog, A., and Nilsson, A. Method for measurement of maximal isometric muscle strength with special reference to the fingers. Upsala Journal Medical Science; 1979, 84(2), 188-194.

KEYWORDS: Isometric muscle strength, fingers.

METHODS: The use of a mechano-elastic transduscer was employed as a pressure transducer. Adjustments were made for measuring finger strength by adjusting to a pressure of 20 kp, thus the range was -20 kp to +20 kp. Abduction and adduction were tested in the metacarpo-phalangial joint at 0° (an extended position).

RESULTS: Reproducibility of muscle strength on the equipment was observed through repeated measures. Variation was found to be greater on the ulnar than on the radial side. Finger muscle strength in normal persons using 27 subjects was observed. This produced a table giving measurements of handedness for men and women, mean and standard deviation pertaining to each digit in opposition, adduction and abduction.

SUMMARY: The experiments presented a method for measuring maximal isometric muscle strength. The apparatus was designed with avoidance of hysteresis in mind. Results produced values for fingers muscle strength for normal people.

CITATIONS: Nine references.

STUDY: Nylind, B., Schele, R., and Linroth, K. Changes in male exercise performance and anthropometric variables between the ages of 19 and 30. European Journal of Applied Physiology and Occupational Physiology; 1978, 38(2), 145-150.

KEYWORDS: Longitudinal study, physical working capacity, muscular strength, physical activity, growth.

METHODS: The purpose is to conduct a longitudinal study in an effort to look at age and effects on physical working capacity, muscular strength, body dimensions, and blood pressure. Fifty-five male subjects were measured on isometric muscle strength, submaximal exercise performance anthropometric measurements and health data. All subjects were examined in 1957-1959 and then reexamined with the same methods at a later date.

RESULTS: The subjects height and weight had increased. Increase in muscular strength for grip of both hands and shoulder pull but not shoulder thrust were recorded as significant. Heart rate declined. The subjects were divided into active and inactive groups upon the reexamination, there were differences in the before and after heart rate measures. Going from increasing to decreasing heart rate were four groups, the active-active, inactive-active, active-inactive and inactive-inactive. The first and last groups showed increases in weight and skinfold measures of the abdomen, while the other two groups remained about the same.

SUMMARY: The weight increase was the largest change of the subject due evidently to fat tissue increase. In agreement with earlier research, there was the same increase in strength. Heart rate was as good at 30 as at 19. The authors suspect the subjects used may have been a self select group of individuals who are more interested in their health than those who declined.

CITATIONS: Twelve references.

STUDY: Nyquist, G.W. and Murton, C.J. Static bending response of the human lower torso. Proc. Stapp Car Crash Conference, 19th; 1975, 513-541.

KEYWORDS: Saggital fleximent extension.

METHODS: The purpose was to define bending responses of the lower torso to aid in designing dummies and for response definitions for mathematical modeling. Six male subjects were administered a battery of 72 tests. The tests were to define the response characteristics for saggital flexion and extension. This included muscle tensing and knee bending. The equipment consisted of immobilizing the subjects legs leaving the torso free. All subjects were placed on their side, with the torso lying on a dolly to allow movement. In relation to the skeletal structure, film analysis targets were attached to the subject and filmed during the experimental session. Each subject had a force applied to their shoulders causing the torso to bend at the hip and joint which was analyzed.

RESULTS: All subjects were found to bend through two designated points of the male pelvic crest when struck from behind on the shoulders. As representative of the population, the subjects represented the 18 to 98 percentiles.

SUMMARY: Different responses are obtained depending on whether the lower torso is relaxed or tensed. Bending the knees at right angles to the legs as opposed to having the legs straight significantly increased the range of motion from 120° to 143° in the thorax-pelvis range and from 44° to 68° in the pelvis. Subjects could withstand a maximum flexion of 5,450 lb. in. (616 N m) and maximum extension of 2,170 lb. in. (240) N m).

CITATIONS: Three references.

STUDY: Olson, V.L., Smidt, G.L. and Johnston, R.C. The maximum torque generated by the eccentric, isometric, and concentric contractions of the hip abductor muscles. Physical Therapy Journal; 1977, 52(2), 149-158.

KEYWORDS: Maximum torque, eccentric contraction, isometric contraction, concentric contraction, hip abductor muscle.

METHODS: The right hip abductor muscles of thirty normal male subjects were tested for maximum voluntary eccentric, isometric, and concentric muscle contractions. Two trials were run for each contraction type and the mean of the two trials was multiplied by 55 percent of the thigh length. The result was the torque produced by the abductor muscle for each type of contraction. The three types of contractions were compared at 10 degree (0.17 rad) intervals. Twelve of the thirty subjects had roentgenograms taken at each of the 10 degree intervals so that the moment arm distance of the abductor muscles could be determined and tension calculated.

RESULTS: The maximum torque produced by an eccentric contraction was 1180.9 kg.cm. at 10 degrees (0.17 rad) of adduction. Maximum torque produced by an isometric contraction was 1054.1 kg.cm. at 10 degrees of adduction. For a concentric contraction, maximum torque was 730.7 kg.cm. The maximum tension produced by eccentric, isometric and concentric contraction was 278.1, 224.7, and 154.4 kg. respectively at 10 degrees of adduction for eccentric and isometric contraction and zero degree for concentric contraction.

SUMMARY: Measurement of torque generated by the hip abductor muscles during eccentric, isometric, and concentric muscle contractions were obtained for thirty male subjects. The results indicated that: 1) a shortened muscle produces less tension than a muscle in a lengthened position, and 2) the eccentric contraction develops the greatest tension, then isometric and finally concentric contractions.

CITATIONS: Twelve references.

STUDY: Osternig, L.R. Optimal isokinetic loads and velocities producing muscular power in human subjects. Archives of Phys. Med. and Rehab. 1975; 56(4), 152-155.

KEYWORDS: Extremities; muscle contraction

METHODS: The purpose of the research was to determine the maximal power of load and velocity during isokinetic muscular contractions. Additionally, the author wished to relate these values to isometric effort. Sixteen males, aged 18 to 24 from the University of Oregon football team were subjects. A Cybex Dynamometer was used to take the measurements of maximum isokinetic and isometric torque values during leg extension. Velocities used were 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5 and 25 rpm for isokinetic torque while isometric measures were taken at angles of 50°, 55°, 60°, 65°, 70°, 75°, 80°, and 85°. The peak value for each angle was used to represent that particular point in the arc of motion. The power was calculated using the equation:

$$\text{Power} = \text{TX rpm}/5252$$

T = torque : with results in units of horse power
rpm = speed
5252 = a constant

RESULTS: Mean isometric torque decreased from a high 172.30 ft. pounds at 85° to a low of 101.44 foot pounds at 50°. Different patterns of velocity resulted depending on the angle of extension. Maximum torque at each joint angle increased with velocity as the leg became more vertical.

SUMMARY: The maximum power produced was found with decrease in the knee angle. Maximum isometric loads varied up to 40.89% through the same arc. A plateau of isokinetic torque was reached at the speeds of 17 to 24 rpm. Thus, there may be uniform isokinetic torque values which result in a maximum power at certain ranges of limb movement. The author believes it is possible for the leg momentum helped to overcome leg weight during leg extension thus resulting in higher peak torques during decreasing angles.

CITATIONS: Fifteen references.

STUDY: Osternig, L.R., Bates, B.T., and James, S.L. Isokinetic and isometric torque force relationships. Archives Phys. Med. Rehab., 1977, 58(6), 254-257.

KEYWORDS: Elbow joint, exercise test, exercise, muscle contraction.

METHODS: The purpose was to look at the forces generated during isokinetic and Isometric efforts to determine the relationship between the two. Twenty-eight male football players, ages 18-22 years, were used. Maximum isometric and isokinetic measures were taken on the elbow using a dynamometer. Angles of the elbow measured were 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90° at speeds of 5, 7.5, 12.5, 15, 17.5, 20, 22.5, and 25 rpm. The elbow angle was flexed at 155° and pushed to full extension. Correlations were calculated between the maximum isometric torque and corresponding isokinetic torque angles.

RESULTS: Thirteen of the 81 correlations were significant at the $p<.05$ level. There was no pattern found regarding distribution of the correlations. A tendancy for the higher coefficients of the slower isokinetic speeds clustered toward the large elbow angles.

SUMMARY: The results are in agreement with those found in previous research. Why the cluster is found toward the greater angles is not understood. The author speculates the cause may be a result of the greater muscle tension generated when muscles are stretched. The author feels that measures of maximal isokinetic cannot predict isometric strength.

CITATIONS: Twenty references.

STUDY: Patton, R.W., Hinson, M.M., Arnold, B.R., Jr., and Lessard, B. Fatigue curves of isokinetic contractions. Arch. Phys. Med. Rehabil; 1978, 59(11), 507-509.

KEYWORDS: Sex differences, isokinetic, fatigue, elbow flexors.

METHODS: The purpose was to study isokinetic fatigue curves and if there was sex differences in the curves at different strength levels. Sixteen men and sixteen women, aged 18 to 24 were used. The equipment used was Orthotron. Based on torque produced, each group was evenly divided into high strength (HS) and low strength (LS) groups. The LS males and HS females were found to be equal on the testing of elbow flexion of the preferred arm. The flexions were continued by the subject to exhaustion (when the subject was unable to perform another contraction).

RESULTS: Each of the four groups developed significantly ($p<.01$) different rate of fatigue. The mean torque values were the same for the HS females and the low strength males. Fatigue was seen as the torque differed significantly from the subjects initial torque position. All groups except the LS females showed this change.

SUMMARY: The isokinetic exercise was seen to follow a curvilinear pattern until sex and strength levels were controlled, which resulted in negative linear slopes. The use of 50% torque for the inducement of fatigue seems appropriate.

CITATIONS: Seven references.

STUDY: Pearn, J. Two early dynamometers: An historical account of the earliest measurements to study human muscular strength. Journal of the Neurological Sciences; 1978, 37(1-2), 127-134.

KEYWORDS: Dynamometer, muscle strength measurement.

SUMMARY: This paper is a review of two of the earliest dynamometers, together with results of the first experiments attained with them. The Graham-Desaguliers dynamometer was developed in London in 1763 to measure human muscular force, in such a way that synergistic muscles could not impart a false mechanical advantage to the test. The Regnier dynamometer was invented in Paris in 1798 to measure the traction properties of artillery-horses, but was designed as an all-purpose instrument to measure specific human muscle groups as well. Dynamometers were developed to record human strength along a continuum, to remove the need for a dead-weight or biological standard, and to measure many different groups of muscles, not just those of lifting or pushing.

CITATIONS: Seventeen references.

STUDY: Pedotti, A., Krishnan, V.V., and Stark, L. Optimization of muscle-force sequencing in human locomotion. Mathematical Biosciences; 1978, 38(1-2), 57-76.

KEYWORDS: Muscular knematics, gait, leg.

METHODS: The purpose was to look at sequence of muscles used in a gait. The problem is first stated mathematically for torque, muscular knematics, alternative of instantaneous maximal force in the muscle, constraints and performance criteria. A subject walked over a 15 meter walkway using his own usual gait. Markers were placed at the hip, knee, ankle and metatorsophalangeal joints. A film photographed the gait. A force plate measured ground reaction which was converted on a computer. Muscle EMGs were recorded. Two subjects were used, AC and WM.

RESULTS: The performance of AC and WM were compared. The EMG data for both subjects show agreement with force patterns of earlier research. Descriptions for 11 muscle actions are given. Force patterns were compared to the EMG recordings which resulted in eliminating some of the mathematical equations. Basically, the force measurements were in good agreement with the EMG. The subjects showed similar kinematic variables, but different torques causing different motion between the two. Individual muscle differences between the two subjects are pointed out.

SUMMARY: The force patterns when compared showed similar characteristics. The use of EMG, torque, and kinematic data on the same subject is thought to eliminate many errors in the data when using the three together. The study cannot be generalized to prosthetic devices or patterns of gait other than normal walking.

CITATIONS: Thirty-two references.

STUDY: Perrine, J.J. and Edgerton, V.R. Muscle force-velocity and power-velocity relationships under isokinetic loading. Medicine and Science in Sports; 1978, 10(3), 159-166.

KEYWORDS: Force-velocity vs. load-velocity, position and velocity-specific forces, instantaneous power output, excitation intensity, neuromuscular inhibition.

METHODS: The purpose is to measure acceleration rates such that muscle force may be determined at given positions. Using an isokinetic dynomometer then, direct measurements may be made at lower-velocities of the force velocity relationships of some muscles in-vivo. Ten male and female subjects, aged 18 to 38 years, were tested on knee extensions at a 30° angle and velocities of movement ranging from 0-288°/sec. A Cybex II dynomometer was used for measurement. Subjects were encouraged to reach their maximum force before reaching the 30° angle. Two testing sessions were conducted each on separate days.

RESULTS: The range each subject produced in the 30° torque-velocity outputs was found to be essentially the same. When the speed was low, the mean torque level was fairly uniform with the isometric measurements. For the three highest velocities, the mean torques fell with the velocity. As velocity increased, the knee-extensor power increased.

SUMMARY: The in-vivo muscle relationship appears to have a curve quite similar to that found in previous studies using isolated muscle. The lower speeds were found to result in relatively the same torque values at the 30° angle. The authors believe that man inhibits himself in his force-velocity relationship such that without this inhibition, isolated muscles may appear to perform at higher levels.

CITATIONS: Nine references.

STUDY: Petrofsky, J.S. and Lind, A.R. Aging, isometric strength and endurance and cardiovascular responses to static effort. Journal of Applied Physiology; 1975, 38(1), 91-95.

KEYWORDS: Age, heart rate, blood pressure.

METHODS: The purpose was to assess changes in heart rate and blood pressure of men while performing a static effort and how age may have an effect on this. One hundred men, screened for cardiovascular and blood pressure problems, participated. Each subject performed two trials of maximum static effort on a hand dynomometer. He then exerted 40% of his maximum strength as long as he could maintain tension. Heart rate was continually recorded on ECG and blood pressure was measured at one minute intervals. The men were divided into four age groups.

RESULTS: No difference in strength was found among the groups. No significant difference regarding endurance was found. Heart rate increased in all four groups during exercise, but the largest increase was in the 20-29 year-old groups. Systolic blood pressure increased significantly ($p<.05$) for the oldest group (age 50 years and above). Cardiac work (a product of heart rate and blood pressure) and time-tension index (the myocardial oxygen consumption) increased with work and returned to normal after the exercise was completed.

SUMMARY: The results of strength ability do not agree with the existing literature which indicates a decline in strength with an increase in age. The author feels this may be due to the homogeneity of the subjects. The previous results may be done to subject self-selection of occupation, the choosing of less demanding work with age increase. The results found in the systalic blood pressure are thought to be due to the decrease in elasticity found with age.

CITATIONS: Sixteen references.

STUDY: Petrofsky, J.S. and Lind, A.R. Isometric strength, endurance, and the blood pressure and heart rate responses during isometric exercise in healthy men and women, with special reference to age and body fat content. Pflugers Arch. European J. of Physiology; 1975, 360(1), 49-61.

KEYWORDS: Isometric strength, endurance, aging, exercise performance, blood pressure, heart rate, sex differences.

METHODS: One hundred male and 83 female acted as subjects. Isometric strength and endurance were measured on a portable strain-gauge and hand dynamometer. Strength was taken to be the larger of two brief (2-3S) maximal voluntary contractions (MVC). After a rest of 5 minutes, isometric endurance was measured as the duration of a sustained hand grip contraction at a tension of 401 MVC.

RESULTS: Isometric hand-grip strength was greater in men than in women. In both sexes, age was inversely related to isometric strength, particularly in women. Body fat content, however, was directly related to strength. In contrast, both male and female subjects aging was directly related to isometric endurance while body fat content was now inversely related to isometric endurance. The increase in heart rate throughout a fatiguing contraction at 40% MVC was strikingly similar in men and women. The blood pressure at the end of the 40% MVC was directly related to the resting blood pressure. However, aging and body fat content both increased the resting systolic blood pressure in men and women.

SUMMARY: The relationship of sex, age and body fat content were assessed on the maximal voluntary strength (MVC), the endurance of a sustained contraction held at 40% of the subject's maximal strength, and the associated changes in blood pressure and heart rate.

CITATIONS: Twenth-one references.

STUDY: Petrofsky, J.S., Rochelle, R.R., Rinehart, J.S., Burse, R.L., and Lind, A.R. The assessment of the static component in rhythmic exercise. Europ. J. Appl. Physiology; 1975, 34(1), 55-63.

KEYWORDS: Exertion, static exercise, dynamic exercise, mechanical efficiency, isometric endurance.

METHODS: Three young, healthy men volunteered to act as subjects. The subjects worked on a bicycle ergometer at known fractions of their maximal aerobic capacity (max VO_2). The rate of their pedalling was varied from 30 to 90 rpm, so that for a given percent of max VO_2, the belt tension varied inversely with the speed of cycling.

RESULTS: At any one speed of cycling, isometric endurance decreased as the belt tension increased. Following exercise at 30 rpm, the isometric endurance was 25 to 50% lower than that found at the most advantageous speed of cycling for the subjects; at these faster rates of cycling two subjects showed least static component following exercise at 90 rpm while the remaining subject performed best after cycling at 50 rpm.

SUMMARY: A new approach has been devised to assess the static component of dynamic exercise. This technique involves the measurement of the isometric endurance of muscles which have just taken part in rhythmic exercise and depends on the repeatability of trained subjects in isometric effort. The premise is that isometric endurance will be inversely related to the static component of the preceeding dynamic exercise.

CITATIONS: Nineteen references.

STUDY: Pipes, T. V. Variable resistance versus constant resistance strength training in adult males. European Journal of Applied Physiology and Occupational Physiology; 1978, 39(1), 27-35.

KEYWORDS: Strength, strength training, constant resistance (CR), variable resistance (VR), body composition changes with training, concept of specificity.

METHODS: The purpose was to research constant resistance and variable resistance differences in training and how these differences may affect body composition, anthropometric measures, and muscular strength. Thirty-six males, ages 18 to 26 years were each assigned to one of three groups. The groups (constant resistance, variable resistance and control) were each from a weight training program. Training lasted ten weeks. The two groups who were actually working were working at 75% of their strength. Anthropometric measures, fat, body density and body weight were taken before and after the program.

RESULTS: The CR and VR groups increased significantly over the control group with the CR group increasing the most. When a variable resistance procedure was used to assess stength changes, the VR group had the most change. The training groups did have changes in body composition, lean body weight, absolute and relative body fat, and increases in limb circumferences.

SUMMARY: For strength increases, there was found to be a difference in the training methods. The training did produce expected body changes and these changes were about the same for each group.

CITATIONS: Twelve references.

STUDY: Pipes, T.V. and Wilmore, J.H. Isokinetic vs. isotonic strength training in adult men. Med. and Science in Sports; 1975, 7(4), 262-274.

KEYWORDS: Isokinetic strength, isotonic strength, strength training, body composition changes with training.

METHODS: Thirty-six male volunteers were randomly assigned to one of four groups: isotonic, isokinetic low speed contraction, isokinetic high speed contraction, and control. Each of the training groups performed the bench press, biceps curl, leg press and bent rowing. Training frequency averaged three days per week, with an average duration of 40 min. per day. A series of anthropometric measurements were taken at the beginning and at the end of the training period, including seven skinfold thicknesses (mm) and 10 circumferences (cm). Five motor performance tests were administered.

RESULTS: The results demonstrated a clear superiority of the isokinetic training procedure over the isotonic procedures relative to strength, anthropometric measures and motor performance tasks. The three training groups exhibited similar changes in body composition. The isokinetic high speed group demonstrated the greatest gains overall.

SUMMARY: The present study has revealed that isokinetic resistance training procedures are significantly better in affecting changes in muscular strength, body composition, and motor performance tests than standard isotonic resistance training procedures.

CITATIONS: Twenty-six references.

STUDY: Poppen, N.K. and Walker, P.S. Forces at the glenohumeral joint in abduction. Clinical Orthopaedic and Related Research; September, 1978, 135, 165-170.

KEYWORDS: Clenohumeral joint, abduction, muscles.

METHODS: Three fresh upper quarter cadaver specimens from normal males were used. Speciman one was clamped upright with a rectangular metal bar fixed in the elbow. This allowed the arm to be held at each angle of abduction. An anterior radiograph was taken at each angle with location of bone was marked with pins. Muscles were stripped with origins and insertions being marked with pins. Elastic wires were replaced for the muscles, the angles were taken with radiographs. This allowed lines of action to be drawn on the radiograph. The same was done for specimens two and three, except the wires were sutured to the centers of the muscles and their radiographs were taken. The angles were compared to those of normal living subjects.

RESULTS: Supraspinatus was found to act as an elevator of the arm and compressed the humeral ball into the center of the glenoid. Anterior and middle deltoids increased their lever arms with abduction, thus at high angles they were good elevators. The posterior deltoids role was that of a compressor. Forces at the glenohumeral joint was found to increase linearly with abduction reaching a maximum of .89 times body weight at 90° of abduction. After 90° abduction, there is a reduction of force to .4 times body weight at 150° abduction. The humeral head at 0° subluxed downwards, at 30-60° it had a tendency to sublux upward at 90°, the ball pressed directly into the center of the glenoid. External rotations caused increase in compression and decrease in shearing while, internal rotation showed a magnitude increase while angles to the glenoid face were decreased.

SUMMARY: This study determined the forces in the glenohumeral joint for isometric abduction. This was in the plane of the scapula. Three specimens were used to obtain lines for actions. "The main assumption made in analysis was that the force in a muscle was proportional to its area times the integrated electromyographic signal."

CITATIONS: Sixteen references.

STUDY: Poulsen, E. Prediction of maximum loads in lifting from measurement of back muscle strength. Prog. Phys. Therapy; 1970, 1(2), 146-149.

KEYWORDS: Maximum lifting capacity, back muscle strength, sex differences.

METHODS: The validity of the predictive formula of the maximum weight to be lifted = 1.4M-1/2 body weight (where M can be measured by having the subject pull maximally on a dynamometer), has been tried out in a series of experiments performed on 25 women and 21 men, aged 17 to 62 years, weighing from 40 to 90 kg. In all subjects body weight and back muscle strength were measured. From these data the theoretically predicted maximum weight was calculated. A wooden box 30 x 35 x 25 cm was loaded with approximately the predicted weight. By adding or subtracting weight on the box, the maximum weight that could be lifted was found.

RESULTS: The results indicated that men can, at all body weights, lift more than women. For identical back muscle strength, men can lift more than women by 8 to 10 kg. Also, the men are able to lift heavier burdens than the women at identical predicted lifts. The author concluded that neither a fixed standard load, nor a load related only to body weight, will be satisfactory. A maximum lift predicted from the back muscle strength, however, seems to give realistic values.

SUMMARY: For occasional lifting, it may be recommended that both men and women lift up to 70% of the maximum, which can be determined from the simplified formulas:

Maximum Load = Back Muscle Strength (for men)

Maximum Load = Back Muscle Strength-8kg (for women).

For repetitive lifts, an upper limit of 40-50% of the maximum load should be recommended.

CITATIONS: Five references.

STUDY: Poulsen, E. Studies of back load, tolerance limits during lifting of burdens. Scand. J. Rehabil. Med. (SE); 1978, 10(6), 169-172.

KEYWORDS: Maximum lifts, maximum acceptable load, male and female workers.

METHODS: Fifty men and women of different ages were tested for the maximum isometric muscle strength they could exert on a strain gauge dynamometer. The subjects lifted a box with approximately the maximum load less 5 kg. They used the knee-action technique in lifting. By adding or subtracting loads to the box, the actual maximal load which the subject could just lift from the floor to an upright position was found.

RESULTS: It was found that correlation between body weight and the maximum load the subject could lift was low (r=0.1 - 0.3), while there was good agreement between the maximum load and the back muscle strength (r=0.7 - 0.8). The regression lines for maximum strength and maximum load were different for men and women, men being able to lift heavier loads than women with the same measured back muscle strength. Maximum permissible single lifts have been given for women and men of various ages and body heights.

SUMMARY: The relationship between maximum lifting capacity and the back muscle strength had been established. Also, the maximum acceptable loads for lifting by male and female workers were given. The investigator concluded that muscles rather than ligaments should overcome the gravitational pull, and the strength of the back muscles, in particular of the lumbar erectores spinae consequently must be of great importance for the magnitude of the weights that a person can lift from the floor.

CITATIONS: Seven references.

STUDY: Rasch, P.J. and Pierson, W.R. Some relationships of isometric strength, isotonic strength, and anthropometric measures. Ergonomics; 1963, 6, 211-215.

KEYWORDS: Elbow strength, isotonic, isometric, anthropometric measurement.

METHODS: The purpose is to look at the relationship of isometric scores, weight lifting ability before and after training and anthropometric measurements. Twenty seven men had their upper arm measured by plethysmography and isometric strength of the elbow flexors and extensors was made using a Baldwin-Lima SR-4 load cell. Each subject was trained for one week, then exercised three days a week for six weeks increasing weight lifted when they felt they could.

RESULTS: Weight fell out as an important determinant of arm volumn and girth, with height being minor. The increase in weight lifted before and after training was significant ($t = 7.64$) but not in isometric tension ($t = 1.05$).

SUMMARY: The correlation between weight and arm strength is lower in untrained men than trained men. There was no relation between upper arm girth and elbow strength.

CITATIONS: Eleven references.

STUDY: Rohmert, W. Problems in determing rest allowances. Part 1: Use of modern methods to evaluate stress and strain in static muscular work. Appl. Ergonomics; 1973, 4(2), 91-95.

KEYWORDS: Static muscular work, muscular fatigue, rest allowances.

METHODS: The rest allowance was determined as the time required to remove any remainder fatigue resulting from static muscular work (i.e., where different working periods of holding 50% of the maximal torque (f/F_{max}) of the lower arm alternated with different resting periods).

RESULTS: A sufficient rest allowance (R.A.) in static muscular work was found to depend on force (f/F_{max}) and duration (t/T_{max}) of muscular contraction in the manner of an exponential function according to the formula:

$$R.A. = 18.\left(\frac{t}{T}\right)^{1-4} \cdot \left(\frac{f}{F} - 0.15\right)0.5 \cdot 100 \text{ percent}$$

if $f/F < 0.5$.

SUMMARY: Definitions were given for the terms of fatigue, recovery and degree of fatigue. The rest allowance necessary in static muscular work was given in the manner of an exponential equation as well as by means of graphs.

CITATIONS: Seven references.

STUDY: Royce, J. Isometric fatigue curves in human muscle with normal and occluded circulation. Research Quarterly; 1958, 29(2), 204-212.

KEYWORDS: Grip squeezing muscles, static strength, endurance, occlusion of blood flow, hand dynomometer.

METHODS: Twenty-four young men were tested four times in a balanced series, twice while the blood flow to forearm was occluded with a pressure cuff around the arm, and twice without occlusion. The experiment time was 90 sec.

RESULTS: The initial strength averaged 43.3 kg. No difference was found between the shape of the fatigue curves under the two conditions during the first fifty seconds of the isometric contraction, where the tension had not yet dropped as low as 26 kg. From this factual observation, it may be concluded that virtually no circulation can have occurred in the contracted muscle up to this time. Thus, a tension of 26 kg is visualized as defining the point where internal muscle pressure and blood pressure just balance each other (at 60 percent of maximal force). Below this critical level, circulation does flow through the non-occluded muscle, since there is relatively little fatigue beyond this point. In contrast, the occluded muscle continues to fatigue.

SUMMARY: By observing the fatigue curve under isometric contraction, no difference was found between the two conditions. The author concludes the lack of difference indicates there is no circulation occurring in the contracted muscle during the first 50 seconds. After this point the occluded muscle begins to fatigue while the unoccluded muscle does not.

CITATIONS: Seven references.

STUDY: Salter, N. The effect on muscle strength of maximum isometric and isotonic contractions at different repetition rates. Journal of Physiology; 1955, 130, 109-113.

KEYWORDS: Isometric and isotonic, male and female, muscle strength.

METHODS: The purpose was to compare effects of training on isometric contractions with training of isotonic contractions. Isometric contractions were measured with a strain gauge dynamometer and modified for isotonic measurements. Twelve males and eight females, ages 17 to 48 years, were used for four weeks, four days a week. A test for muscle strength improvement was performed once each testing day.

RESULTS: Training produced significant improvement in muscle strength, but there was no difference between the different methods. The test contractions alone were not sufficient to produce significant change in muscle strength.

SUMMARY: Training resulted in improvement of muscle strength and no correlation was found between degree of muscle strength improvement and fatigue experienced in training.

CITATIONS: Seven references.

STUDY: Sargeant, A.J. and Davies, C.T.M. Forces applied to cranks of a bicycle ergometer during one-and two-leg cycling. Journal of Applied Physiology; 1977, 42(4), 514-518.

KEYWORDS: Exercise, muscle.

METHODS: The purpose is to compare one and two leg cycling in regards to force applied and work performed. Four males were used. Each pedaled on a Van Dobelin-type bicycle ergometer at 50 rpm. Oxygen uptake (VO_2 and cardiac frequency (F_h)) were measured continuously. Force was measured on each pedal and measurements were taken from the first peak over the last two minutes, thus making the mean peak force (MPF). A second method of measuring force was used on the 15° marker positions. The area between these positions was then calculated on the assumption of a constant speed and mean force.

RESULTS: VO_2 was higher in the one-leg condition than the two leg condition consistently. The right and left legs exerted no significant difference in the MPF when running simultaneously. However, where each leg was run individually the right tended (3% greater peak force) to exert more force than the left. Work on the cranks reflect a positive force on the first 180° and a negative force in the second 180° except during high work load.

SUMMARY: All subjects can be considered a part of the normal population as all had cycled as children and none were professional cyclists. Work load was arrived from the work exerted on the pedal (the first 160°) and the work to lift the leg in flexion (the second 160°). This work load did not change between one and two leg work. It is proposed that the increased force used in the one-leg pedaling is less efficient than two leg pedaling.

CITATIONS: Seventeen references.

STUDY: Seireg, A. and Arvikar, R. J. A mathematical model for evaluation of forces in lower extremeties of the musculo-skeletal system. Journal of Biomechanics; 1973, 6(3), 313-326.

KEYWORDS: Lower extremities.

METHODS: The purpose was to develop a model which would be used to predict forces produced in the lower extremeties during various postures. A list of 29 muscles of the lower extremeties were considered important. Some muscles had to be modeled as two parts because of a muscles dual connector or insertion points. Heights of each part of the lower extremeties including their center of gravity were also used. Equations for each body segment for force and moment were given. Objectives were formulated to help in selecting the best equations to use.

RESULTS: A numerical value can be obtained which indicates whether the subject is standing erect, leaning forward or leaning backward. Verification of the models was obtained by gathering EMG data on a subject in different postures. Values were also obtainable for the stooping posture.

SUMMARY: A pattern of EMG signals can be used as a qualitative measure of the muscle forces. Weighting factors were developed and presented in table form. The developed mathematical model is found to be consistant with anatomical observations.

CITATIONS: Thirty nine references.

STUDY: Shaver, L.G. Maximum dynamic strength, relative dynamic endurance, and their relationships. Research Quarterly; 1971, 42(4), 460-465.

KEYWORDS: Maximum dynamic strength, endurance time.

METHODS: Forty male college students were tested for maximum dynamic strength, absolute dynamic endurance, and relative dynamic endurance on the bench press lift. Maximum strength was the load with which one complete movement could be performed using maximum muscular exertion. Absolute dynamic endurance was measured by the number of times a common load of three-fourths of the group's mean maximum dynamic strength could be lifted. Relative dynamic endurance was measured by the number of times an individually determined load representing three-fourths of the subject's maximum dynamic strength could be lifted.

RESULTS: The study indicated that the individuals with the greatest dynamic strength significantly ($p<.01$) have the greatest absolute dynamic endurance (coefficient of correlation = .93). The correlation between maximum dynamic strength and relative dynamic endurance obtained from the present data was -.19 ($P<.01$).

SUMMARY: The data in the present investigation reveal a strong correlation between maximum dynamic strength and absolute dynamic endurance. The data also indicate that when subjects were required to lift a load equivalent to 75% of their maximum strength as many times as possible, there was no relationship with the maximum dynamic strength. The definitions of strength and endurance in relation to methodology and type of equipment used by previous researchers were given in tabular form.

CITATIONS: Eight references.

STUDY: Shaver, L.G. The relationship between maximum isometric strength and relative isotonic endurance of athletes with various degrees of strength. Journal of Sports Medicine and Physical Fitness; 1973, 13(4), 231-237.

KEYWORDS: Isotonic and isometric strength, endurance, elbow.

METHODS: The purpose of the study was to study the relationship between maximum isometric strength and muscular endurance of the elbow. to study the relationship between people having low or high maximal strength in relation to isotonic endurance, and to graph the patterns of isotonic endurance of different groups. Thirty-eight males divided into two groups of the strongest and weakest subjects were used. Each were tested for maximum isometric strength and isotonic endurance of the elbow. The isometric strength was taken by a Clarkes cable tensiometer method. A modified arm-lever ergometer was used to test isotonic strength with the range of motion between 45° and 160° (as measured from the horizontal plane) at 35 rpm rotated on percentage of strength at 35, 40 and 45% of maximum isometric strength.

RESULTS: Athletes with the highest maximum strength had the highest endurance. The high and low groups differed significantly ($p<.05$) in strength. There was a significant correlation for the entire group between isometric strength and isotonic endurance.

SUMMARY: The study indicates that persons with high maximal isometric strength have also high isotonic endurance when using 35, 40 and 45% of this maximum strength. It is suggested that isotonic endurance tests at given percentage levels can differentiate between groups of athletes.

CITATIONS: Fourteen references.

STUDY: Shephard, R.J. A brief bibliography in fatigue and fitness. Journal of Occupational Medicine; 1974, 16(12), 804-808.

KEYWORDS: Physiological fatigue, psychological fatigue, neuromuscular impulses, physical fitness.

METHOD: The purpose is to cover the aspects of physical fitness which help to prevent psychological and physiological fatigue.

Physiological fatigue: Possible causes may be attributed to buildup of lactic acid, blockage of neuromuscular impulses at the junctions and/or a breakdown of electrical impulse. It is suggested that aids be used if necessary in working equipment such that no more than 40-50% of the operators energy is in use. In addition when the work load is figured other aspects of the work environment such as temperature, high peak rate, posture and use of small muscle groups should be considered.

To prevent physiological fatigue fitness can be improved through aerobic power, strength gains, improved posture, changing body fuel and improving thermoregulation. Psychological fatigue is noted as the worker asking for a change in work rather than a rest period. The causes may be boredom or tediousness of the task. Those have been recorded physiological reactions to psychological fitigue which includes such symptoms as sweating, discomfort associated to task aversion and listleness, lack of vigor, drive and determination was associated with lack of motivation. Fitness training such as habituality to discomfort, exercise to elevate depressed moods, arousal and motivation can help to counteract the psychological aspects.

SUMMARY: While fatigue is caused by several factors these can be changed with physical fitness program.

CITATIONS: 63 references.

STUDY: Singh, M. and Buck, T.M. Leg-lift strength test with electrogoniometric analysis of knee angle. Arch. Phys. Med. Rehabil.; June, 1975, 56(6), 261-264.

KEYWORDS: Extremities, knee, muscles, physical medicine, physical therapy, rehabilitation.

METHODS: An electrically operated dynamometer with attachments was used. An electrogoniometer was attached to the subject's knee for measurement of angle. The equipment was connected in a way to enable continuous recording of leg left score and knee angle. Four test methods were used: a) no restriction on backward lunging and usual reduction bar and belt, b) prevent lunging, c) prevent lunging and eliminate use of hands, and d) experimental bar and belt used, prevent lunging and allowed use of hands. Four trials on each test method with one minute rests were given, each subject was tested on four different days.

RESULTS: Most accurate scores (least variability) was found in method C. An ANOVA reflected differences in knee angle changes due to a) type of belt, and b) no restriction of lunging.

SUMMARY: Authors feel the leg-lift strength test is feasible for use as a diagnostic test to assess the condition of the leg extensor muscles. A physical therapy plan could then be established using the test results.

CITATIONS: Eleven references.

STUDY: Singh, M. and Karpovich, P.V. Isotonic and isometric forces of forearm flexors and extensors. Journal of Applied Physiology; 1966, 21, 1435-1437.

KEYWORDS: Dynamometer, electrogoniometer, strength test.

METHODS: The purpose was to design an electrical dynamometer which could record and measure isotonic and isometric forces and study isometric forces of the forearm to determine relationship between forces and prediction of one force from another. The dynamometer had a force of 150 ft-lb and used 4 SR-4 type strain gauges. The subject can be stabalized in position. An electrogoniometer was attached to the axis of rotation to measure angles form 40 to 50°. The force exerted would be continuously recorded every 20° from 50 to 140° for the forearm flexors and extensors. Twenty males were subjects tested twice not more than 24 hours apart. The maximum affective eccentric, isometric and concentric forces of the forearm were recorded.

RESULTS: The eccentric force of the forearm flexors is significantly greater that isometric and concentric forces throughout the range of movement. The concentric and eccentric forces correlated significantly at the .01 level. The eccentric force is significantly less than the isometric force from 100 to 140°.

SUMMARY: The forearm flexors at various angles was significantly related to concentric, eccentric and isometric forces. The results of the study agree with previous research. Six equations for the force curves were developed.

CITATIONS: Five references.

STUDY: Smidt, G.L. Biomechanical analysis of knee flexion and extension. Journal of Biomechanics; 1973, 6(1), 79-92.

KEYWORDS: Knee joint, extension, flexion.

METHODS: The purpose is to look at torque generated at the knee extensors and flexors for concentric, eccentric, and isometric muscle contractions. Twenty-six men, mean age 28 years, were used. Serial lateral radiographs were taken on the knee joint and torque generated by the knee flexors and extensors. The x-rays were taken in a series of seven, starting with the knee angle at full extension, continuing at 150° intervals and ending at 90°. Each subject performed both tasks while lying on a table with the leg supported by sandbags. A load cell dynagraph and tape recorder were used to obtain the force data. Moment equilibrium equations were used to obtain the measure of tension in the flexors and extensors. Anthropometric measurements were taken.

RESULTS: Reliability was obtained on the same day by test-retest measures. The peak correlations for eccentric extension was .69, .72 for eccentric flexion, .72 for concentric extension, and .69 for concentric flexion. The range for isometric extension was .64-.92 and .60-.80 for isometric flexion. The x-ray film measurements were .80 or above for flexion and extension. Torque generated knee extensors was always higher than that of knee flexors. Eccentric and isometric contractions produced about the same amount of torque.

SUMMARY: The measurements taken allowed for analysis of the knee joint regarding flexion and extension.

CITATIONS: Twenty-two references.

STUDY: Soechting, J.F. and Roberts, W.J. Transfer characteristics between EMG activity and muscle tension under isometric conditions in man. J. Physiol. Paris; 1975, 70(6), 779-793.

KEYWORDS: EMG, isometric contractions, transfer function.

METHODS: Four male subjects, ranging in weight from 43 to 89 kg. were used. The subjects were to exert tension charges which varied sinusoidally about non-zero mean, using either the flexors or extensors of the upper arm. An audible signal, consisting of a frequency modulated plus train, was also provided to aid the tracking task at the higher modulation frequencies. Surface electrodes were taped on the skin over either the biceps brachii or the long head of the triceps brachii or both. The reference electrode was located on the skin at the cubital fossa. The data were calculated in terms of the gain and phase difference of the motor activity (input) and tension (output) relationship, the gain being the logarithmic ratio of the amplitudes of the output and input sinusoids.

RESULTS: It was found that an increase in the modulation amplitude of the motor unit activity was required to produce the same amount of modulation of the output tension as the modulation frequency was increased. It was found that the maximum tension which could be produced voluntarily during brief jerks at 5 Hz was the same as the maximum sustained tension which could be attained.

SUMMARY: The relationship between motor unit activity and a voluntarily produced, sinusoidally modulated isometric tension was evaluated as a function of the modulation frequency. The findings of the study emphasized the importance of recruitment and especially synchronization of motor unit activity to the graduation of output tension.

CITATIONS: Twenty-two references.

STUDY: Start, K.B. and Graham, J.S. Relationship between the relative and absolute isometric endurance of an isolated muscle group. Research Quarterly; 1964, 35(2), 193-204.

KEYWORDS: Elbow flexors, isotonic, isometric, endurance.

METHODS: Isotonic Contractions: Occured when the distance between the origin and insertion alters during the development of muscular tension (either concentrically or eccentrically).

Isometric Contractions: Occurred when the distance between muscle origin and insertion remains constant for the period of tension.

Isotonic Endurance (I.T.E.): Measured as work done against gravity in terms of the load and the distance through which the load is moved. In practice I.T.E. is measured as the function of the work done in a simple isotonic effort and the number of times this simple movement is repeated.

Isometric Endurance (I.M.E.): Is the ability of the muscle group to maintain a given tension for a period of time and involves a continuous effort by the muscle rather than a series of repeated efforts.

Absolute Isometric Endurance (A.I.M.E.): Can be defined (or measured) as the number or seconds the muscle group can maintain a fixed tension.

Relative Isometric Endurance (R.I.M.E.): Can be measured as the number of seconds the muscle group can maintain a tension that is a specific proportion of its maximum isometric strength.

This study used 30 males with an age range of 18-26 years. The body position during measuring the I.M.E. was as indicated in the figure. The angle at elbow was 115°. Two measures of endurance were taken. The first was A.I.M.E. used a common load of 50 lbs. (approx. 5/8 of the mean of the maximum strength of the group). The second was R.I.M.E. used an individual load of 5/8 of the maximum strength recorded for each particular member in the group.

RESULTS: A significant (.01 level) correlation between the M.I.M.S. and A.I.M.E. was +0.749 ($\pm$0.08). The correlation between M.I.M.S. and R.I.M.E. was -0.356 ($\pm$.159). This was not significant at the .01 level.

Start and Graham 1964 Cont.

RESULTS CONT: Start and Graham (1964) suggested the following formula to represent the factors affecting endurance:

$$E = f(S) + f(L.C.E.) + f(t)$$

where:

E = muscular endurance
f = function of
S = muscular strength
L.C.E. = Local Circulatory Efficienty
T = tolerance of muscle to katabolites.

Factors Affecting Endurance: The intramuscular pressure, probably in the normal muscle, and almost certainly in the trained muscle, rises above the arterial pressure in that muscle. As a result, occlusion occurs of the arteries, capillaries, and veins within the muscle and the energy for any sustained contraction comes aerobically from whatever oxygen reserve there is in the muscle and anaerobically as long as glucose is available and the muscle tissue can tolerate the build-up of the resultant anaerobic katabolic products. It is clear that greater debt occurs in isometric exercise than in isotonic effort of the same magnitude. Thus the measures of isometric endurance are probably estimates of the energy reserve available within the muscle and its neurological organization.

In low load conditions the intramuscular pressure never exceeds systolic pressure and arterial blood enters the muscle, making additional glycogen and oxygen available to the contracting fibers. Because of the valvular construction of the veins, blood also leaves the muscle, taking with it the waste products of the contraction and thereby reducing the local chemical irritation of the muscle issue. At this level of loading, muscle endurance would be determined by the local reserves of the muscle, the intramuscular circulation, and the local tissue tolerance to katabolites. Once the overall reserves are exhausted or the build-up of katabolites reaches a critical concentration, "local muscular fatigue" would occur.

As the muscle has to endure increasing loads the tension it has to develop correspondingly increases and this produces a rise in the intramuscular pressure until circulatory occlusion occurs and local ischaemia results. From this point of

Start and Graham 1964 Cont.

RESULTS CONT: intramuscular circulatory occlusion, the amount of energy the muscle has available is fixed by the aerobic reserves at the time of occlusion, the anaerobic reserves, and the tissue tolerance limitation on anaerobic release. Thus if the ischaemic muscle is considered, it has a fixed amount of energy available and can use this slowly or quickly according to demands. The time taken to use this energy is what is measured as endurance and, in the ischaemic muscle, endurance becomes related to the energy available and the demands made on it.

SUMMARY: The authors looked at differences in measures between isometric and endurance strength. Each subject was measured for strength of the group mean and individual mean. The authors suggest that isometric exertions cause vascular occlusion. Thus when dynamic exertion allow circulation then the relationship between isometric and dynamic strength decreases.

CITATIONS: 24 references.

STUDY: Start, K.B., Gray, R.K., Glencross, D.J. and Walsh, A. A factorial investigation of power, speed, isometric strength and anthropometric measures in the lower limb. The Research Quarterly; 1966, 37(4), 553-559.

KEYWORDS: Anthropometric measures, isometric strength, strength in legs.

METHODS: The purpose is to look at measures of strength, speed, power, and gross lever dimensions of the legs to investigate the element of muscle power. Sixty-three males were given a series of physical measures on the legs, ranging from anthropometric to power jumps and a speed test on a bicycle ergometer.

RESULTS: Intercorrelations between measures ranged from .54 to .82. Varimax factors ordered the measurements with the tests for power and speed being Factor 1. Factor 2 was predominately the anthropometric measurements. Factors 3, 4, and 5 were strength tests on the joints. Factor 6 was foot length and malleolus to heel measure. Factor 7 was thigh and limb length and Factor 8 was weight and speed. The second order factors are reviewed.

SUMMARY: Speed and power appear to be most similar with little association with strength.

CITATIONS: Twenty references.

STUDY: Stern, J.T., Jr. Computer modelling of gross muscle dynamics. J. Biomech; 1974, 7(5), 411-428.

KEYWORDS: Moment arm, exerted force, velocity of contraction, angle between bones, time elapsed.

METHODS: A mathematical model incorporating mechanical and physiological parameters of an idealized bone-muscle system has been devised. When the model is numerically integrated by digital computer, the movement of a limb under the action of a muscle is simulated.

RESULTS: It is found that for most comparisons the model predicts an optimum set of attachment sites for maximizing anyone given dynamic movement parameter. The optimum moment arm for high velocity of movement is relatively small, that for greatest power somewhat larger, and that for producing a specified motion in the least time larger still. These and other predictions of the model are compared to the actual disposition of muscles in living organisms.

SUMMARY: Based on the premise that the physiological attributes of muscle must play an important role in determining its dynamic functions in the body, an attempt has been made to integrate mechanics and physiology into a mathematical model that, when used in conjunction with a digital computer, allows one to simulate the movement of a limb under the action of an idealized muscle. This method of analysis has been used to investigate the suggested dichotomy between adaptation for speed or strength in the disposition of muscles about joints.

CITATIONS: Seventy references.

STUDY: Stull, G. A. and Kearney J. T. Recovery of muscular endurance following submaximal isometric exercise. Medicine and Science in Sports; 1978, 10(2), 109-112.

KEYWORDS: Isometric endurance, isometric fatigue, muscular endurance, muscular fatigue recovery, rhythmic exercise, static exercise, submaximal endurance.

METHODS: The purpose was to assess submaximal endurance recovery with various rest intervals 22 males mean age 21.8 $\pm$ 4.09 years were used. Each subject was tested 11 times with intervals of 3 days between trials. Each subject was to squeeze a hand dynamometer which was connected to a Baldwin-Lima-Hamilton U-1 load cell and a Beckman Type RS Dynograph recorder recorded the readings. A maximum voluntary contraction (MVC) was taken on each subject and then with feedback the subject attained 50% of the MVC. Each subject held the 50% MVC with rest intervals of 5, 10, 20, 40, 80, 160, 320, 640, 1280, and 2560 seconds.

RESULTS: Recovery time of the muscles 20% in 5 seconds, 50% in 80 seconds and 87% in 42 minutes 40 seconds. a mathematical equation on recovery time was offered. Correlation between observed and expected times was .997.

SUMMARY: The recovery followed a three component exponential patterns. For complete recovery after a submaximal test, such as this one, then 4 hours would be needed for complete recovery.

CITATIONS: Nineteen references.

STUDY: Svoboda, M. Influence of dynamic muscular fatigue and recovery on static strength. The Research Quarterly; 1973, 44(4), 389-396.

KEYWORDS: Static strength, endurance, forearm flexors, arm ergometer.

METHODS: The purpose was to look at fatigue effects on two muscle groups of a task and to observe recovery of the subjects. A Henry frictions-loaded arm ergometer was used to measure the dynamic strength. The subject performed as long as possible. Static strength was taken three times before the subject began dynamic work. A control group was used which rested during the work cycle. Subjects were their own controls. 60 male college students were used.

RESULTS: From start to finish in the dynamic work there was a 33% drop off in work rate. A low significant relationship found between static strength and endurance.

SUMMARY: The work rate dropoff the endurance was not parallel to the static strength dropoff although they both reflected a significant relationship, although minor.

CITATIONS: Fifteen references.

STUDY: Tesch, P. and Karlsson, J. Lactate in fast and slow twitch skeletal muscle fibres of man during isometric contraction. Acta Physiol. Scand.; 1977, 99(2), 230-236.

KEYWORDS: Fiber Composition, isometric strength.

METHODS: Concentrations of the lactate in fast and slow twitch fibres were determined in the quadriceps femoris muscle after sustained contractions at 25%, 50% and 75% of maximal voluntary isometric contraction (MVC) until exhaustion as well as after interrupted exercises at 25% and 50% MVC. Biopsies for determination of muscle fibre lactate concentration were taken immediately after termination of exercise (within 3-5 seconds) with the subject still sitting in the chair.

RESULTS: The mean performance time at 75, 50, and 25% MVC, respectively, averaged .55 (range .46-.7) minutes, 1.7 (range .92-1.42) minutes and 4.63 (range 3.4-5.9) minutes. With exhaustive exercise mean lactate concentration was highest after 50% MVC in ST as well as FT fibres, 86 (range 37-128) and 96 (range 44-130) in moles kg^{-1} dry weight respectively. Lactate concentration was higher in slow twitch (ST) fibres at 50% MVC compared to it in ST fibres at 25% MVC and higher in fast twitch (FT) fibres at 50% MVC compared to in FT fibres at 75% MVC.

SUMMARY: After short time, isometric exercise (i.e., 75% to exhaustion and 50% and 25% performed for the same period of time as 75% MVC) lactate concentration, expressed as lactate ratio (lactate concentration in FT fibres/lactate contration in ST fibres) was found to be positively correlated to percent FT fibres (r=0.89). Lactate ratio ranged 0.51-0.99, i.e., at onset of isometric exercise, lactate concentration increase was faster in ST fibres in the muscle rich in ST fibres and faster in FT fibres when the muscle was rich in FT fibres.

CITATIONS: Twenty-four references.

STUDY: Tesch, P. and Karlsson, J. Isometric strength performance and muscle fibre type distribution in man. Acta Physiol. Scand; 1978, 103(1), 47-51.

KEYWORDS: Fast twitch, slow twitch, muscle fiber, maximal isometric strength.

METHODS: The purpose was to study one-leg maximal isometric strength (MIS) using Hultin et al. (1975) experimental model. 31 males average age 21 years, were used. Biopsies of the left leg vaslus lateralis muscle were taken and slow twitch (ST) and fast twitch (FT) muscles were identified. Subjects were tested for strength (where biopsies were takers again) using a strain gauge.

RESULTS: A correlation between FT and ST distribution and the one-leg MIS was found.

SUMMARY: The results indicate the use of FT fibres during high isometric tensions. The study does not support the idea that concentrations of FT muscles fibre mean more strength.

CITATIONS: Nineteen references.

STUDY: Thorstensson, A., Grimby, G., and Karlsson, J. Force-velocity relations and fiber composition in human knee extensor muscles. J. Appl. Physiology; 1976, 40(1), 12-16.

KEYWORDS: Isokinetic contraction, isometric and dynamic muscle tension, human skeletal muscle fiber type distribution, knee extensor muscles.

METHODS: Standardized measurements of dynamic strength of the knee extensor muscles were performed in 25 healthy male subjects (17-37 yr.) by means of isokinetic contractions, i.e., knee extension with constant angular velocity. Muscle fibers were classified as fast twitch (FT) and slow twitch (ST) fibers.

RESULTS: Overall variation between double determinations of maximal torque throughout the 90 degrees are of motion (0 degrees=fully extended leg) averaged 10% for the different constant velocities chosen. At any given angle of the knee the torque produced was higher for isometric than for dynamic contractions. Dynamic torque decreased gradually with increased speed of shortening. Peak dynamic torque was reached at knee angles in the range: 55-66 degrees, with a displacement toward smaller knee angles with higher angular velocities. Correlations were demonstrated between peak torque produced at the highest speed of muscle shortening and percent as well as relative area of fast twitch fibers in the contracting muscle. In addition, muscles with a high percentage of fast twitch fibers had the highest maximal contraction speeds.

SUMMARY: The use of the isokinetic principle proved to be a valid way of studying force-velocity relations. Peak torque was found to decrease with increased angular velocity, and to occur at an approximate knee angle of 60 degrees. The correlation present between peak torque produced at the highest angular velocity and the portion fast twitch fibers indicates a role for muscle quality in terms of fiber types, in determing dynamic strength in certain situations.

CITATIONS: Twenty-five references.

STUDY: Thorstensson, A., Karlsson, J., Vittasalo, J.H.T., Luhtanen, P., and Komi, P.V. Effect of strength training on EMG of human skeletal muscle. Acta Physiol. Scand.; 1976, 98(2), 232-236.

KEYWORDS: Strength training, isometric muscle strength, EMG, fibre composition.

METHODS: The effects of an 8 weeks period of systematic progressive strength training on the EMG activity of the leg extensor muscles (vastus lateralis and rectus femoris) were investigated in 8 healthy male subjects (22-31 years).

RESULTS: After training there were indications (not significant) of a decline in integrated EMG (IEMG) during maximal isometric knee extension as well as in the IEMG vs. isometric force relationship. The averaged motor unit potential (AMUP) did not demonstrate any significant changes due to the strength training regimen. In conformity with earlier findings no or only minor alterations were observed in anthropometrics, muscle enzyme activities and fibre composition. The fibre area ratio indicated a specific effect of the training stimuli on the fast twitch (FT) muscle fibre.

SUMMARY: EMG-analysis, as employed in the present study, did not provide any conclusive additional explanation as to the mechanisms behind the well established gains in muscle strength performance induced by the applied strength training program.

CITATIONS: Fifteen references.

STUDY: Thorstensson, A., Larsson, L., Tesch, P., and Karlsson, J. Muscle strength and fiber composition in athletes and sedentary men. Medicine and Science in Sports; 1977, 9(1), 26-30.

KEYWORDS: Isokinetic contractions, static and dynamic muscle tension, muscle fiber type distribution, trained and untrained human muscle.

METHODS: The authors propose to look at strength performance in athletes of different disciplines and sedentary men under standardized isokinetic conditions. Subjects used were track and field, downhill skiing, racewalking, orienteering and a sedentary group. Measurements were taken in post season time for all athletes except the skiers. Biopsies from m. vastus lateralis were taken. Muscle strength measurements were taken using the seated subjects left leg attached to the lever arm of a Cybex II isokinetic dynamometer. Two maximal contractions at six different velocities and six different knee angles were taken. All strength measurements are given in kg. of body weight or percent of the individual maximal isometric force.

RESULTS: The sprinters/jumpers had the highest percent of fast twitch fibers (x=61%) while the sedentary men had a mean of 56%. The race walkers and orienteers showed the lowest percentage, fast twitch being 41% and 33% respectively. The fast twitch to slow twitch ratio was a significant difference between the sprinters/jumpers and sedentary/orienteers only. A difference between the groups was found in the torque-velo-velocity curves, with the greatest peak torque in the downhill skiiers and sprinter/jumpers (3.9 & 3.8Nm/kg bw) with the orienters being lowest (3.1 Nm/kg bw) at isometric contractions. At the 180 degree velocity, the track athletes recorded the highest peak (2.7 Nm/kg bw) and the orienters were lowest at 1.7 Nm/kg bw. For the highest speeds, the track athletes again produced the highest torque values (73%). It was found that the relative peak torque production for track athletes was highest at the fast velocity than as indicated by their fiber compositions.

SUMMARY: Slow twitch fibers were found to be predominate in endurance athletes which agrees with previous reports. The reasons for the skiiers and sprinters/jumpers to have higher peak torque cannot be stated conclusively as due to training and/or genetic predisposition. It can be stated that: 1) the percentage distribution of the two fiber types is genetically determined as stated by previous research and, 2) fast twitch fibers are used in high speed movements for high force production. It does appear that training does help the development of fast twitch/slow twitch area ratios. Although the track and field athletes were superior to others on the highest speed, the difference disappeared when compared to isometric strength.

CITATIONS: Twenty-one references.

STUDY: Troup, J.D.G. and Chapman, A.E. The strength of the flexor and extensor muscles of the trunk. J. Biomechanics; 1969, 2, 49-62.

KEYWORDS: Muscle strength, flexor and extensor muscles of trunk, sex differences, static strength, dynamic strength.

METHODS: The forces exerted by the males were significantly greater than those exerted by the females, both in absolute terms and when expressed as a proportion of the body weights of the two sexes. Flexor forces were consistently less in magnitude than extensor forces and flexor turning moments were similarly less than extensor turning moment. The mean distances between fingertips and the plantar surface of the feet achieved in the performance of this test were closely similar in the two sexes. The mean vertical distances moved at the seventh cervical vertebra (C7) in the performance of prone, trunk raising tests were 35.6 cm for both sexes. It was also found that all the forces and all the turning moments in the static tests of strength correlated significantly with each other for both sexes. Finally, the individual measurements of static strength were significantly related to subjects' weight, particularly with the male subject.

SUMMARY: The ratios of flexor to extensor forces in the standing posture were found to be of the order of 3:4 which is in accord with previous studies. The flexor forces exerted and the flexor turning moments were both greater in standing posture than sitting posture. This follows the expected pattern that muscles can transmit greater forces when in a lengthened position. The extensor turning moments on the trunk in the two postures showed no significant difference although the extensor forces were markedly greater when sitting. The relationship between the individual results of the sit and reach, inclined test and the flexor moment sitting, and between those of the prone, trunk raising test and the extensor moment, standing were statistically significant.

CITATIONS: Forty references.

STUDY: Tuttle, W.W., Janney, C.D., and Thompson, C.W. Relation of maximum grip strength to grip strength endurance", Journal of Applied Physiology; 1950, 2, 663-670.

KEYWORDS: Grip force, endurance, dynomometer.

METHODS: Strength Endurance Index: Is defined as the average strength for one minute expressed as pounds.

Percentage of Maximum Strength Held: Is defined as the percentage of the maximum strength maintained for the one-minute period to the maximum strength.

A dynomometer for measuring and recording maximum grip strength and strength endurance was developed. Data were collected from 200 university men between the ages of 20 and 30 years.

RESULTS: A correlation of maximum strength with the strength endurance index gave a coefficient of 0.67 for the right hand, and 0.66 for the left. This indicates that the individuals with greater maximum strength have a greater strength endurance index.

The percentage of the maximum grip strength which was maintained for one minute (strength endurance) was correlated with maximum grip strength. The coefficient for the right hand was -.40 and for the left hand -.41. This suggests that stronger individuals can maintain a smaller proportion of their maximum strength than those with less initial strength.

SUMMARY: Maximum grip strength and maximum endurance was correlated. Measurements were taken on the right and left hands. The results indicate that stronger individuals have lower endurance times in relation to their strength than do the weaker individuals.

CITATIONS: Six references.

STUDY: Velsher, E. Performance feedback effect on results of isometric exercise. Physiotherapy Canada; 1977, 29(4), 185-189.

KEYWORDS: Isometric contraction, performance feedback.

METHODS: This investigation was designed to study whether knowledge of results would influence the amount of strength in the quadriceps femoris muscle over a two-week training period. Twenty-four female undergraduate (17-20 yrs.) were required to perform a six-second maximal isometric contraction with three repetitions per day for ten days. They were divided into four experimental groups, each on a different performance feedback schedule.

RESULTS: Although an analysis of convariance did not show a significant effect, inspection of the post-test means did reveal that with regular feedback more strength was developed.

SUMMARY: The results of this investigation reveal that more strength is developed with the use of visual feedback. Although there does not seem to be any direct relationship between the frequency of knowledge of results and strength increase, it would seem that extrinsic feedback is not necessary at each isometric exercise session in order to provide guidance or incentive.

CITATIONS: Fifteen references.

STUDY: Viitasalo, J.T. and Komi, P.V. Force-time characteristics and fiber composition in human leg extensor muscle. European J. Appl. Physiol.; 1978, 40(1), 7-15.

KEYWORDS: Muscle mechanism, fiber composition, force production, leg extensor muscle.

METHODS: To further understand the problems involved in force production during voluntary contraction, the force-time (F-T) curve was registered during maximal voluntary isometric extension of both legs performed in the sitting position with the knee angle at 107 degrees and a hip angle of 120 degrees. Thirty-eight athletes representing various sport events, five pairs of monozygous, and ten pairs of eight normal men. Each subject had three trials, of which the two best were taken for analysis on the basis of the maximum force level.

RESULTS: In trial-to-trial comparison the reproducibility was r=0.80 for force level below 0.9XP° but only r=0.38 at P°. Similarly the day-to-day comparison in which the interval between the tests was 3-9 days, showed r=0.66-0.76 for the force levels of 0.1XP° to 0.9P° At P° however, the reproducibility coefficient was almost zero (r=0.03). In the male athlete groups the time to reach the various force levels was related to the % ST fibers. In this analysis the ocrrelation coefficient was significant ($p<0.05$) up to the level of 0.9XP°. The athletic groups had F-T curves different from the other subjects. Genetic factors had only slight influence on the F-T measurement.

SUMMARY: Force-time measurement in isometric bilateral leg extension movement is fairly reliable, and can be used to indicate the rate of force production. Skeletal muscle fiber composition influences the form of this F-T curve.

CITATIONS: Twenty-two references.

STUDY: Wahrenberg, H., Lindbeck, L., and Ekhold, J. Dynamic load in the human knee joint during voluntary active impact to lower leg. Scand. J. of Rehab. Medicine; 1978, 10(2), 93-98.

KEYWORDS: Dynamic load, knee joint.

METHODS: The aim of the study was to get insight into the nature of the dynamic load in a joint caused by impacts of physiological magnitude to the distal part of an extremity of normal, live human subjects. A method was developed by the calculation of two components of the impulse reaction (parallel and perpendicular to the lower leg) as a measure of the dynamic load in the knee. A theoretical model regarding the lower limb as a double pendulum was chosen and equations developed. Five male subjects (20-35 yrs.) were used.

RESULTS: The range of the mass moment of inertia of the lower leg is 0.46-0.64 kg.m^2 and for the thigh, 0.39-0.54 kg.m^2. The kinematic data and the calculated components of the impulse reaction in the knee joint are given in tabular form.

SUMMARY: With a normal kicking motion, pattern the direction of the components of the impulse reaction in the knee joint caused by the impact to the lower leg are usually distal and anterior. The impulse reaction thus tends to cause a fraction of the lower leg from the thigh and an anterior displacement of the proximal part of the lower leg in relation to the distal part of the thigh.

CITATIONS: Thirteen references.

STUDY: Wahrenberg, H., Lindbeck, L., and Elkholm, J. Knee muscular movement, Tendon tension force and EMG during a vigorous movement in man. Scand. J. Rehab. Medicine; 1978, 10(2), 99-106.

KEYWORDS: Knee muscular movement, tendon tension force, EMG, dynamic load.

METHODS: Six male subjects, 20-35 years old, were instructed to give a hard kick to an ordinary soccer football (A), a heavy (3 kg) ball (B), and a ball fixed to a wall (C). The subjects were instructed to kick in the sagittal plane. EMG were recorded by means of surface electrodes from m. quadriceps femoris (m. rectus femoris), the hamstring muscles (m. biceps femoris) and m. gastrocnemius. The angular change between thigh and lower leg recorded by an electrogoniometer.

RESULTS: The range of the moments of inertia of the lower leg is 0.456-0.642 kg.m^2. The m. quadriceps produced a maximum moment of magnittude around 200 Nm with respect to the knee axis. The maximum muscular moment occurred early in the sequence of motion in all subjects, when the angle of flexion was 80°-120° (mean 99°). The highest extending muscular moment obtained was 26 Nm (the mean of the highest maximal values of the subjects was 180 Nm). The corresponding calculated highest tension force in the patellar tendon was 5200 N and the mean 3633 N.

SUMMARY: The strength of the muscle tissue appears to be low, and thus the weakest link in the extensor apparatus of the knee might be the muscle. It experiences the same tension as the tendon, i.e., 7 times body weight. This fits in with clinical observation of athletes-partial muscular ruptures are common.

CITATIONS: Nineteen references.

STUDY: Watson, A.W.S. The relationship of muscular strength to body size and somatype in post-puberal males. Irish J. of Med. Science; 1977, 146(9), 307-308.

KEYWORDS: Muscular strength, body size, body shape.

METHODS: The subjects were 52 post-puberal male school boys aged 16 to 18 years. Strength was measured as the sum of left and right hand grip and back strength. Level of habitual activity was assessed from activity diary entries and the somatotype of each subject was determined photoscopically.

RESULTS: Strength was significantly related to all the anthropometric measurements studied (i.e., height, weight, humerus diameter, femur diameter, arm circumference, calf circumference, thigh circumference, chest circumference, BA diameter, BI diameter, BSA, thigh volume, and thigh (mtb) volume. When the body weight of the subjects was statistically held constant strength was positively related to arm circumference, thigh muscle + bone volume, fat free weight and bicondylar diameters of humerus and femur and negatively related to percentage of fat. Strength was related to somatotype components but not to level of habitual activity.

SUMMARY: Multiple regression analysis indicated that about 57 percent of the variance in strength is accounted for by measures of overall size and 26 percent by body shape. The best over-all prediction of strength is given by the equation (R = 0.874):

$$\text{Strength} = 1.01 \text{ humerus diameter} + 3.61 \text{ femur diameter} + 0.733 \text{ arm circumference} + 11.17 \text{ mesomorphy} - 0.425 \text{ calf circumference} - 307.22.$$

CITATIONS: None.

STUDY: Watson, A.W.S. A three-year study of the effects of exercise on active young men. Eur. J. Appl. Physiology; 1979, 40(2), 107-115.

KEYWORDS: Physical working capacity, percent fat, isometric strength, motor ability, somatotype.

METHODS: The subjects were 20 highly active young males aged between 18 and 19 years at the start of the study. The following data was collected on each subject at intervals of six months over a three-year period: height, body weight, hand grip strength, back strength, standing long jump score (S.L.J.), alternate hand wall toss score (A.H.W.T.), Physical Working Capacity at a heart rate of 170 beats per minute (PWC_{170}) and skinfold thickness on four sites. Somatotype was determined once at the beginning of the study.

RESULTS: Body weight and estimated percentage of fat increased over the three-year period but there were no significant changes in the other variables. Within the three-year period, physical working capacity and relative leanness-fatness showed significant variations where are attributed to the state of training of the subjects. Strength was found to be highly related to somatotype, but was apparently not influenced by the state of training; changes in relative leanness-fatness occurring with training were found to be influenced by somatotype.

RESULTS: It is not clear to what extent the present results can be applied to other groups of post-puberal males, since although the body fat content of the present subjects was average they had higher than normal physical working capacities. And being students of physical education they might be expected to be above average in motor ability.

CITATIONS: Twenty-one references.

STUDY: Williams, R. and Seirig, A.A. Interactive computer modeling of the musculoskeletal systems. IEEE Transactions on Biomedical Engineering; 1977, BME-24(3), 213-219.

KEYWORDS: Computer, musculoskeletal structure, jaw.

METHODS: A computer program was developed which is programmed with a model of the human musculoskeletal structure. The user may modify the model and then can get a printout of what the effects on the system would be with the modifications. The model can calculate forces on muscles and joint reactions. The results are given in formula and graphic display. The jaw is given as an explanation of the system.

SUMMARY: The program, the author feels, gives great versatility as the body can be looked at as a whole, or as independent parts. The program has been made as machine independant as possible. It provides simple and manipulative program for the user and adds speed to the tedious task of working with modeling.

CITATIONS: Five references.

STUDY: Williams, M. and Stutzman, L. Strength variation through the range of joint motion. The Phys. Ther. Rev.; 1958, 39(3), 145-152.

KEYWORDS: Maximum isometric contraction, angle of flexion, sex difference, age difference.

METHODS: There were approximately 10 subjects in each of the adult groups tested, and 20 in the childrens' group, 10 boys and 10 girls. Forces were measured at 30 degree intervals through the range of motion of the joint in most cases. A sling attached to a tensiometer was applied to the distal end of the segment.

RESULTS: Isometric joint torque curves were given for: elbow flexion, knee extension, knee flexion, shoulder flexion, shoulder horizontal adduction, and hip adduction. Comparison of men, women and children was also given for knee flexion and hip flexion. The results revealed that in the children's group the boys were stronger than the girls, however, the difference was not statistically significant. The difference in magnitude of the forces between women and children is much less than between men and women.

SUMMARY: Most isometric joint torque curves studies show a continuous drop in strength from the elongated position of the prime movers through their range of motion. Among the exception are elbow flexion, knee extension, and shoulder adduction. Plateaus or levelling off of force variation occur in some of the curves, notably in arm elevation movements.

CITATIONS: Eleven references.

STUDY: Zahalak, G.I., Duffy, J., Stewart, P.A., Litchman, H.M., Hawley, R.H. and Paslay, P.R. Force-velocity-EMG data for the skeletal muscles of athletes. Technical Report. Center for Biophysical Sciences and Biomedical Engineering; Brown University, Providence, RI. November, 1973.

KEYWORDS: Arm flexion and extension, EMG, static and dynamic muscle strengths.

METHODS: A load was applied to the subjects wrist such that the subject could rotate the arm but not move it in any direction. Constant-force springs were used to apply the force. angular positions of the arm was recorded. EMG was used on the biceps and triceps muscles and processed through a model 7 Driver amplifier. Computer was used to record and store data. Six males, 18-19 years old were used. Each subject was oriented with the procedure one day and tested the next. Static and dynamic tests were made.

RESULTS: Load and velocity were found to remain constant within the sampling interval while the scales of EMG for biceps and triceps were different. Increase in EMG found in the isometric conditions was attributed to fatigue. The research indicates an increase of EMG with force.

SUMMARY: While EMG was found to increase with force and velocity it remained independent with velocity in arm extension.

CITATIONS: Eighteen references.

APPENDIX E.

Selected Bibliography

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